JOURNAL OF

THE ROYAL SOCIETY OF WESTERN AUSTRALIA

INCORPORATED

VOLUME 41 (1958)

PART 1

PUBLISHED 19TH MARCH, 1958

REGISTERED AT THE G. P. O., PERTH, FOR TRANSMISSION BY POST AS A PERIODICAL

THE

ROYAL SOCIETY

OF

WESTERN AUSTRALIA

INCORPORATED

COUNCIL 1957-1958

1.—Recent Advances in the Chemistry of Western Australian Plants

Presidential Address, 1956

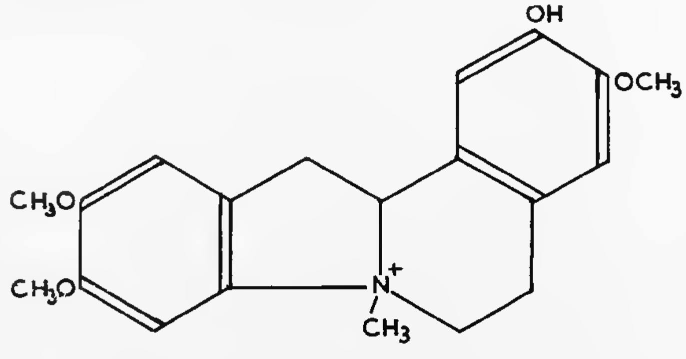
By D. E. White, M.Sc., D.Phil., F.R.A.C.I.*

Delivered 16th July, 1956

Introduction

Twelve years ago, Dr. E. M. Watson (1944) in his Presidential Address to this Society gave us a masterly summary of current knowledge about the chemistry of Western Australian plants. Since that time the investigations initiated by the Drug Panel set up by the Department of Industrial Development of Western Australia (which has now unfortunately lapsed), and by the Australian Phytochemical Survey, which grew from a similar "Drug Plants Survey" in the Eastern States, together with investigations supported by University Research Funds, have added considerably to the knowledge of our native plants. There is still, however, a vast amount of work to be done before we can be said to have explored the chemical potentialities of our flora with anything like thoroughness and I propose to summarise what has been done and to make some observations on what remains to be accomplished.

Rereading Dr. Watson's address, it is somewhat discouraging to see just how many of the promising lines of investigation pointed out by him still remain to be tackled. However, there is some encouragement to be gained from the recommencement of investigations in plant chemistry at the Government Chemical Laboratory and it is to be hoped that these along with investigations in the University and Technical College laboratories will be successful in making a much greater contribution during the next 12 years than I am able to record tonight. Quite substantial progress has been made during the past 12 years in some fields, however. In discussing these I have adopted a primary chemical classification with a sub-classification into plant families.



CRYPTAUSTOLINE
Fig. I.

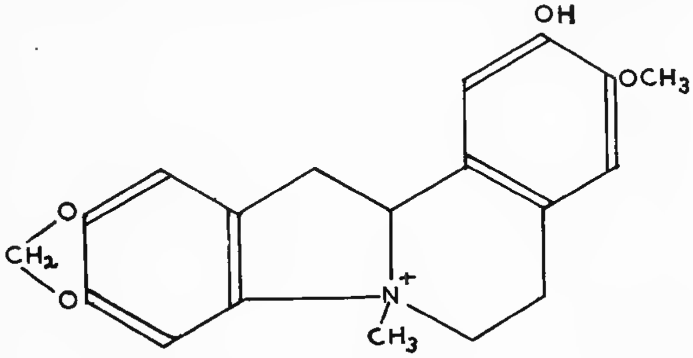
*Chemistry Department, University of Western Australia.

Alkaloids

Lauraceae

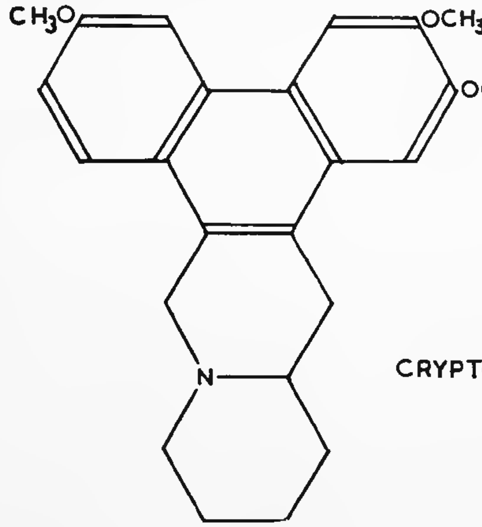
This family is represented in Western Australia by *Cryptocarya glaucescens* R. Br. and by several *Cassytha* species.

Although our *Cryptocarya* has not yet been examined some Queensland species have afforded particularly interesting alkaloids, in recent years. These include the first two dibenzopyrrocolines isolated from plants, cryptaustoline (I) and cryptowoline (II) from *C. bowiei* (Hook.)



CRYPTOWOLINE
Fig. II.

Druce (Ewing *et al.* 1953) and the vesicant alkaloid cryptopleurine isolated by de la Lande (1948) from *C. pleurosperma* White et Francis. Chemical study of this alkaloid was difficult and Gellert and Riggs (1954) were only able to establish the presence of a phenanthrene nucleus and three methoxyl groups.



CRYPTOPLEURINE

Fig. III.

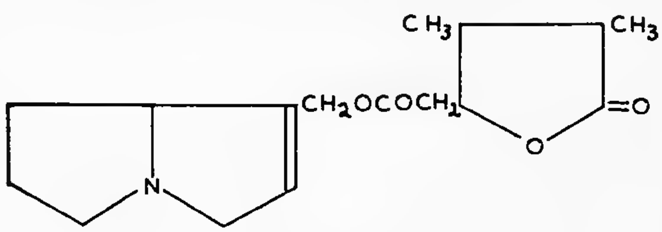
However, the structure of the related *iso*cryptopleurine methiodide was solved in a very elegant manner by Fridrichsons and Mathieson (1955) by X-ray diffraction studies. This demonstrated that *iso*cryptopleurine was a phenanthro-quinolizidine. Gellert (1956) has now shown that *iso*-cryptopleurine is merely the racemic form of the naturally-occurring alkaloid. Hence this is represented as (III).

Alkaloids of the aporphine group have been reported in *C. triplininervis* R.Br. and *C. angulata* C.T. White (Cooke and Haynes 1954). It will be interesting to see if the Western Australian species is related to either of these three types or if it contains some other type of alkaloid.

One of our *Cassytha* species, *C. pomiformis* Nees has been examined and found to contain 0.04 per cent. of crude alkaloid (Bottomley and White 1949). This genus might well repay closer examination.

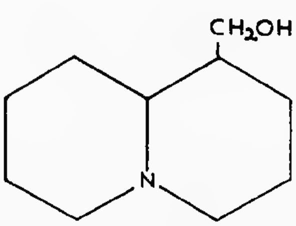
Papilionaceae

Several Western Australian *Crotalaria* species have been found to contain substantial quantities of alkaloids. Monocrotaline (IV) was isolated by Adams and Rogers (1939) from *Crotalaria retusa* L. Current investigations (Culvenor 1956) have confirmed this and in addition found other bases and N-oxides in this species and also in *C. mitchelli* Benth. and *C. trifoliastrum* Willd. It has been shown that *C. retusa* is responsible for Kimberley horse disease and may be the sole cause (Gardner 1952; Gardner and Bennetts 1956).



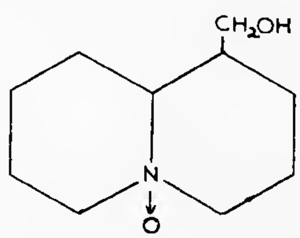
MONOCROTALINE

Fig. IV.



EPILUPININE

Fig. V.



EPILUPININE-N-OXIDE

Fig. VI.

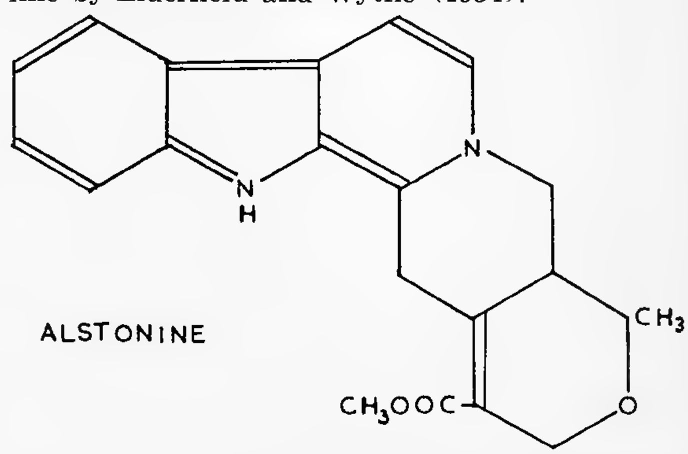
Heavy mortality in sheep grazing on the "Western Australian" blue lupin *(Lupinus varius* L.) during the 1949-1951 seasons led Crow and Riggs (1955) to investigate its alkaloids. They separated four alkaloids by paper chromatography and identified (+) -*epi*lupinine (V), which had been isolated by White (1951) in New Zealand, and also its N-oxide (VI). This was the first recognition of lupinine-N-oxide in nature and is significant because compounds of this type are not isolated by conventional extraction procedures, while they may be responsible for a substantial part of the toxic effect of the plant. The other alkaloids, which appear to be new, have not yet had their structures determined.

Loganiaceae

The Western Australian *Strychnos lucida* R.Br. is, of course, closely related to the well known *Strychnos nux-vomica,* and is found in Northern Australia from Queensland to the west coast. Earlier work summarised by Webb (1948), indicated the presence of strychnine and brucine in the seeds but Bottomley and White (1947) observed that other alkaloids must be present. Shaw and de la Lande (1948) isolated in addition to strychnine and brucine an amorphous alkaloid which they called lucidine-S. They also obtained an alkaloid named lucidine-L from the leaves. Anet, Hughes and Ritchie (1953) isolated and characterised strychnine and brucine in extracts of the seeds and obtained the glycoside loganin, which had previously been found by Merz and Krebs (1937) in the pulp of *S. nux-vomica* fruits and has since been investigated by Birch and Smith (1956). They found a considerable amount of amorphous alkaloid material in their *S. lucida* seeds and considered that their failure to isolate lucidine-S might have been due to its decomposition in the seeds, which were more than a year old when examined.

Apocynaceae

Alkaloids were isolated from the bark of *Alstonia constricta* F. Muell. over seventy years ago by Hesse (1880). However, it was not until the quinine shortage of World War II forced the examination of every possible alternative, that they were closely studied. Although they did not provide any compounds of value as anti-malarials, the constitution of the major alkaloid, alstonine (VII), was established by Elderfield and Gray (1951), and that of alstoniline by Elderfield and Wythe (1954).

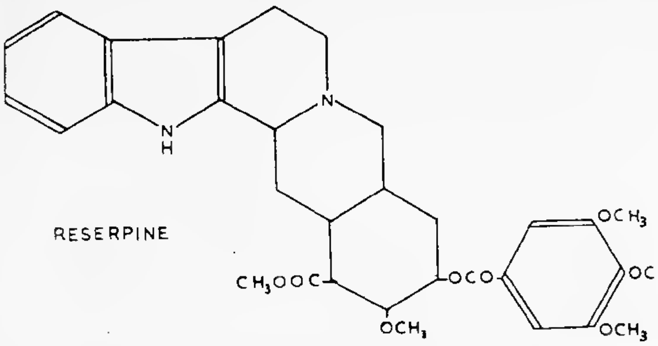


ALSTONINE

Fig. VII.

It was the reported occurrence of alstonine in *Rauwolfia vomitoria* Afzel. and the known botanical relationship of *Alstonia* and *Rauwolfia* species (Crow, 1955) which inspired a reinvestigation of *A. constricta*. As a result Crow and Greet (1955) and Curtis, Handley and Somers (1955) discovered reserpine (VIII) in the root bark. This was an announcement of great importance because of the value of reserpine in the treatment of hypertension and its even greater importance in the treatment of certain

mental disorders. It provides Australia with a convenient native source and makes her independent of the export ban imposed by India and the shortage of supplies from other countries.



RESERPINE

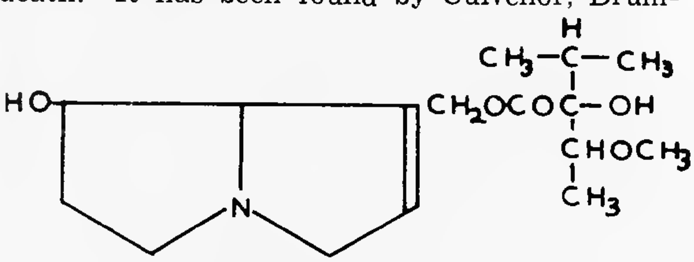
Fig. VIII.

A thorough examination of the two recorded Western Australian *Alstonia* species deserves immediate attention.

A. actinophylla (A. Cunn.) K. Schum. (= *A. verticillosa* F. Muell.) is known to belong to the non-alstonine-yielding group of Alstonias (Sharpe 1934) but little is known of the constitution of the major alkaloid, echitamine or of the other alkaloids which accompany it, and the Western Australian species might well yield reserpine or some valuable related alkaloid.

Boraginaceae

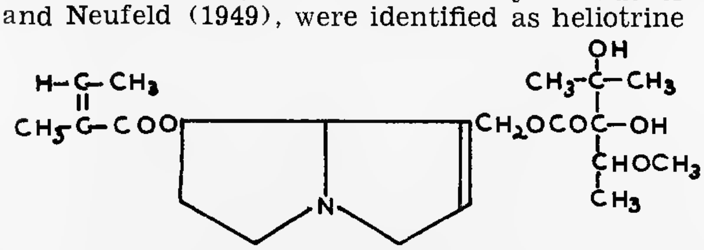
Heliotropium europaeum L. grows in all the southern Australian states and causes liver damage in sheep, frequently resulting in their death. It has been found by Culvenor, Drum-



HELIOTRINE

Fig. IX.

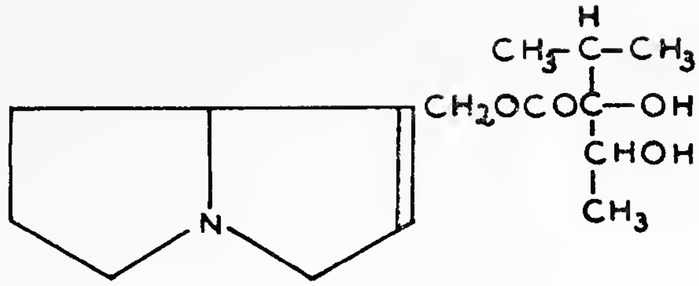
mond and Price (1954) to contain five alkaloidal bases and their N-oxides. The two most abundant bases, first isolated by Trautner and Neufeld (1949), were identified as heliotrine



LASIOCARPINE

Fig. X.

(IX) and lasiocarpine (X) previously obtained by Menshikov (1932) from *H. lasiocarpum*. Culvenor (1954) identified the two minor bases as supinine (XI) and supinidine heliotrate and the third major base as heliotridine lasiocarpate.

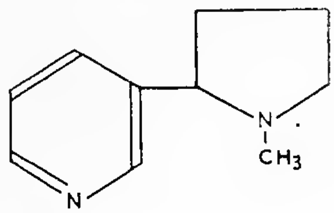


SUPININE

Fig. XI.

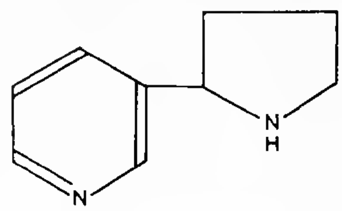
Solanaceae

The long-standing controversy about the alkaloids of *Duboisia hopwoodii* (F. Muell.) F. Muell., dating from the isolation of a product named "piturine" (Bancroft, 1872), has now been resolved. The observations of Rothera (1910), who



NICOTINE

Fig. XII.

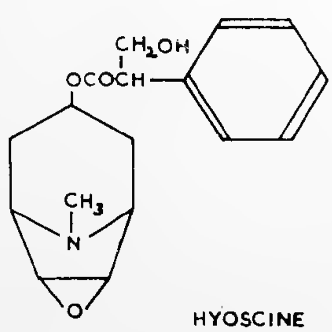


NORNICOTINE

Fig. XIII.

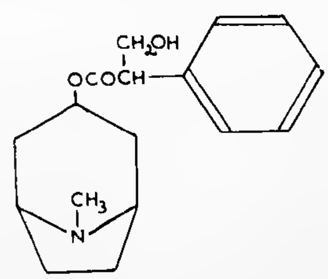
isolated nicotine (XII), and of Hicks and Le Messurier (1935) and Bowen (1944) who obtained nornicotine (XIII), were reconciled by Bottomley, Nottle and White (1945) who showed that most specimens of *D. hopwoodii* contained both nicotine and nornicotine, but in some nicotine was absent. These observations were confirmed and extended by Bottomley and White (1951b), who obtained samples from four sites (of the 34 examined) which resembled the material examined by Hicks and Bowen in not containing any nicotine.

The alkaloid content, estimated on dried leaves, could not be correlated with locality, season or soil type and an examination of fresh leaves showed that there was a considerable loss of alkaloid on drying. These investigations indicated that *D. hopwoodii* is a much more favourable source of nicotine alkaloids than Hosking (1944) believed but the replacement of nicotine by DDT, gammexane and other insecticides has removed a great deal of the demand for it.



HYOSCINE

Fig. XIV.



HYOSCYAMINE

Fig. XV.

It is remarkable that *Duboisia hopwoodii* differs so strikingly in its alkaloid content from *D. myporoides* R. Br. and *D. leichhardtii* F. Muell which contain the tropane alkaloids hyocine (XIV) and hyoxyamine (XV). These species have now been linked by the observation of Loftus Hills, Bottomley and Mortimer (1953) that *D. myoporoides* grown from seed obtained from New Caledonia contains nicotine and nornicotine as well as hyoscine and hyoscyamine. They suggest that this may be a relic of a primitive form from which the genotypes of the Australian mainland originated.

Compositae

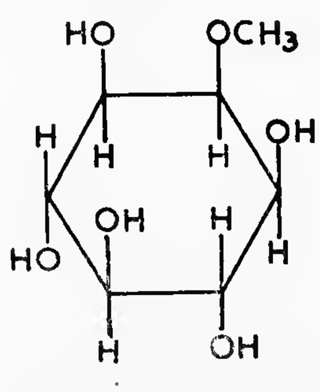
Members of the Compositae which have yielded alkaloids in Australia include *Senecio jacobea* L., which has been studied in Victoria (Bradbury and Culvenor 1954; Bradbury and Willis 1956) because of its known liver-damaging effect on stock.

Western Australian *Senecio* species have not yet been investigated, but *Erechthites quadridentata* D.C. which grows in this state has been found to contain alkaloids of the pyrrolizidine type like *Senecio, Crotalaria,* and *Heliotropium* species. Three alkaloids, senecionine, seneciphylline and retrorsine have been isolated, partly free but mainly as N-oxides (Culvenor and Smith 1955). Like the liver-damaging alkaloids of *Heliotropium europaeum* and the *Crotalaria* and *Senecio* alkaloids they are esters of pyrrolizidine bases.

Non-Alkaloidal Toxic Compounds

Macrozamia spp.

The toxic compound macrozamin was first isolated from the seeds of *Macrozamia spiralis* Miq. by Cooper (1940). Dr. N. V. Riggs obtained the same compound, accompanied by a small amount of sequoyitol for which he proposed the structure (XVI) (Riggs, 1949) from the Western Australian *M. riedlei* (Gaud.) C. A. Gardn. Lythgoe and Riggs (1949) showed that macrozamin was a β-primeveroside of an aglycone $C_2H_5ON_2$



SEQUOYITOL

Fig. XVI.

which contained no readily acetylated grouping and Langley, Lythgoe and Riggs (1951) proposed the two alternative structures (XVII and XVIII). These were substantiated by comparison of its ultraviolet absorption spectrum with the spectra of synthetic azoxy compounds, but it was not possible to decide between them. Further comparisons with the infrared spectrum of azoxymethane were made by Langley, Lythgoe and Rayner (1952) who studied the acid catalysed decomposition of the synthetic azoxy-com-

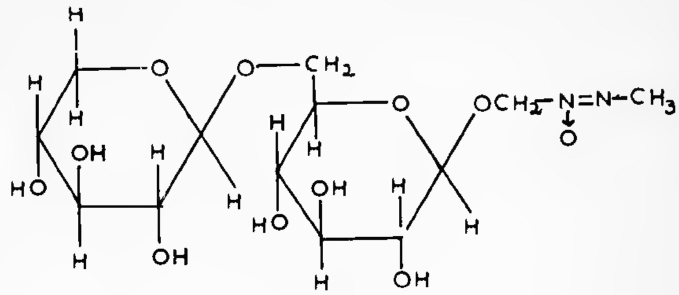
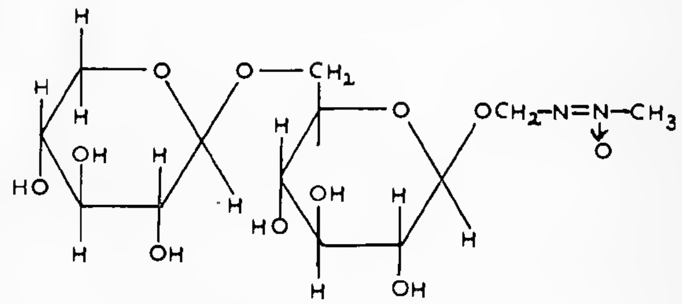


Fig. XVII.



MACROZAMIN

Fig. XVIII.

pounds and concluded that structure (XVIII) was the more likely since the methyl group was oxidised (to formaldehyde) and hydrazine produced, rather than methyl hydrazine. They considered that oxidation would occur at the carbon atom adjacent to the more highly oxidised 4-covalent nitrogen atom.

The same compound has also been obtained by Riggs (1954) from other Cycadaceae including *Cycas, Bowenia* and *Macrozamia* spp. from Queensland, but *M. denisoni* C. Moore seeds did not contain macrozamin or any similar compound.

Oxylobium and *Gastrolobium* spp.

These two genera provide the largest group of Western Australian poison plants with over thirty toxic members (Gardner and Bennetts, 1956.) In spite of intermittent study over more than 50 years we are still unable to say what is the cause of their toxicity.

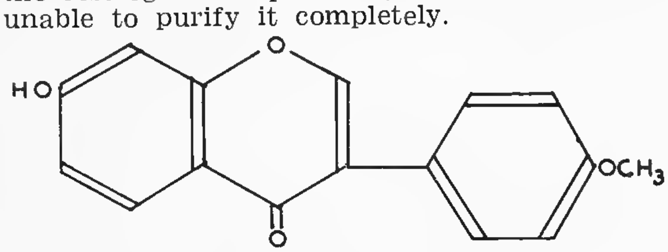
They were reinvestigated by Bottomley (1950) who obtained highly toxic concentrates from the seeds of *Oxylobium granticum* S. Moore. However, the small amounts of alkaloids extracted from these were non-toxic and reduction failed to disclose any N-oxides. The water solubility of the toxic material made examinatin by the conventional methods difficult but application of countercurrent extraction and partition chromatography to the extracts should give interesting results and perhaps solve this intriguing problem, which in 1907 was thought to have been solved by the isolation of alkaloids (Mann and Ince, 1907).

Heterocyclic Oxygen Compounds

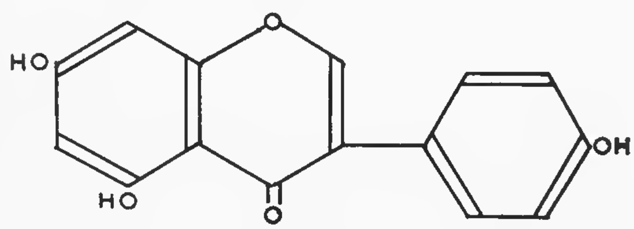
Genistein

One of the most widely used plants in improved pastures in Western Australia is subterranean clover (*Trifolium subterraneum* L.). Considerable attention was given, therefore, to the demonstration by Bennetts (1944, 1946, 1947) and Bennetts, Underwood and Shier (1946) that it was responsible for poor lambing results and for the loss of many ewes maintained on subterranean clover pastures. Its seriousness is indicated by the fact that lambing may fall below 10 per cent., while loss of ewes may reach 30 per cent., on pastures dominated by the early Dwalganup strain.

Curnow, Robinson and Underwood (1948) showed that the effect was caused by some oestrogenic or oestrogen-producing substance in the plant. Its activity was relatively low as one hundred millionth of a gram of oestradiol would produce a similar effect to one gram of dried clover. However, Curnow (1950) and Beck and Braden (1951) were able to prepare concentrated extracts and demonstrated that the oestrogen was phenolic, although they were unable to purify it completely.



FORMONONETIN
Fig. XIX.

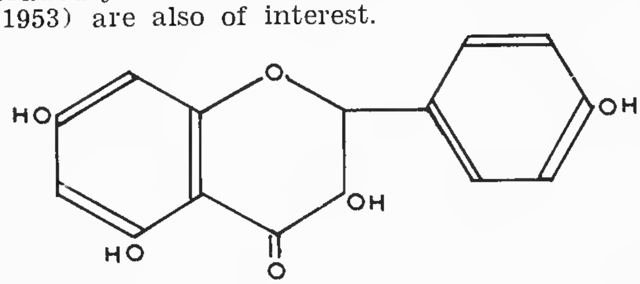


GENISTEIN
Fig. XX.

Bradbury and White (1951) omitted the alkali-treatment used by the previous authors, since this was known to cause decomposition of the oestrogen, isolated from *Butea superba* (Schoeller, Dohrn and Hohlweg, 1940). Using chromatography on alumina to separate compounds from the alcoholic extract, two *iso*flavones, formononetin (**XIX**) and genistein (**XX**) were isolated and genistein was shown to be a weak oestrogen. Biggers and Curnow (1954) estimated that it was between 1/100,000th and 1/16,000th as active as oestradiol depending on the method of administration and showed that it fell into the class designated as pro-oestrogens by Emmens (1941), since it was little more effective when applied directly to the vagina than when injected. This contrasts strongly with the steroid oestrogens which are more than 100 times as effective on local application.

Curnow (1954) showed that the Dwalganup strain of subterranean clover contained more than 0.7 g. of genistein per 100 g. of dry matter and that half of this could be recovered on extraction. From this he concluded that there was sufficient genistein in the plant to account for its oestrogenic activity although he pointed out that treatment with alkali appeared to produce a more active oestrogen.

Meanwhile, it had been shown that some other clovers had similar but less powerful oestrogenic effects and Pope *et al.* (1953) in England isolated a methyl ether of genistein (biochanin-A) from red clover (*Trifolium pratense* L.) and showed that it was weakly oestrogenic. This compound has also been isolated in further studies of alkali-treated extracts of subterranean clover (Beck, Kowala and White, 1956), together with several inactive compounds and probably two other oestrogens, which have not yet been obtained in sufficient quantity to enable their constitutions to be determined, but which are much more active than genistein. Even if they are artefacts these compounds may indicate the structural type of the true oestrogen formed from genistein in the animal body. In this connection the synthetic oestrogens prepared by Bradbury and White (1953) and by Bradbury (1953) are also of interest.



AROMADENDRIN
Fig. XXI.

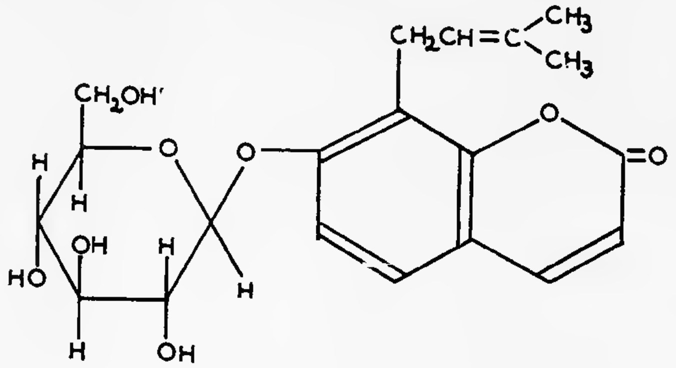
Aromadendrin

The red kino exuded from the bark of *Eucalyptus calophylla* R. Br. is responsible for its common name "Redgum" and from this kino H. G. Smith (1896) isolated a colourless crystalline compound which he called aromadendrin. Its structure has now been determined as a dihydrokaempferol (**XXI**; Hillis, 1952.) Hillis has found this compound in a large number of eucalypt kinos, and overseas investigators have found it and related compounds in a variety of plants (references quoted by Hillis, 1952; Gripenberg, 1952; Tominaga, 1953.) It seems that compounds like this may form with the flavones, flavonols, leucoanthocyanidins, anthocyanidins and catechin-like compounds a complex oxidation-reduction system which might be of profound importance in plant metabolism.

Vellein

The toxicity of *Velleia discophora* F. Muell. (Goodeniaceae) to stock (Gardner and Bennetts, 1956) led to its chemical examination. Bottomley and White (1951a) isolated from it the glycoside vellein, which they identified as the β-glucoside of osthenol (**XXII**). This

structure was confirmed by synthesis of tetraacetylvellein from O-tetraacetyl-α-glucosidyl bromide and osthenol.



VELLEIN
Fig. XXII.

Vellein is accompanied by a smaller amount of another coumarin named discophoridin (Bottomley, 1950), the structure of which has not been elucidated.

Neither of these compounds has yet been subjected to pharmacological testing.

Essential Oils

The essential oils of Australian plants attracted attention from the time of the first settlement in New South Wales, when the Surgeon to the First Fleet, Dr. White, distilled the oil from *Eucalyptus piperita* Sm. and noted its peppermint odour. H. G. Smith was largely responsible for the systematic examination of many of these oils and extended his collections to Western Australia. Subsequently many chemists in Australia and overseas have contributed to this field which was until a few years ago the only one in which a really substantial amount of work on Australian plant chemistry had been accomplished.

However, the investigation of the oils of Western Australian plants has not been nearly as extensive nor as thorough as could be wished and there are many large gaps in our knowledge.

Coniferae

No new chemical investigations of Western Australian members of this family have been reported since Watson's summary (1944) with the exception of the publication of Murray's observations (1950) on the leaf oil of *Callitris Morrisoni* R. T. Baker, the major constituents of which are pinene and limonene.

With the recognition of the 7-membered ring tropolones in overseas members of the Coniferae it would seem well worthwhile to reinvestigate the wood-oils of our species. Interest has also been added by a recent report of the presence of tumor-damaging compounds in extracts of *Podocarpus* and *Callitris* spp. (Hartwell 1956).

Santalaceae

The most important contribution to the chemistry of this family has been the elucidation of the structure of the sesquiterpene alcohol lanceol which occurs in *Santalum lanceolatum* R. Br. Bradfield *et al.* (1936) proposed a unique 5-membered ring structure (XXIII) for this compound but it has now been shown to be related to the known monocyclic sesquiterpene bisabolene (Birch and Murray 1951; Eschenmoser, Schreiber and Keller 1951). It probably has one of the two structures (XXIV) or (XXV) although Eschenmoser, Schreiber and Keller also consider an 8-membered ring possible.

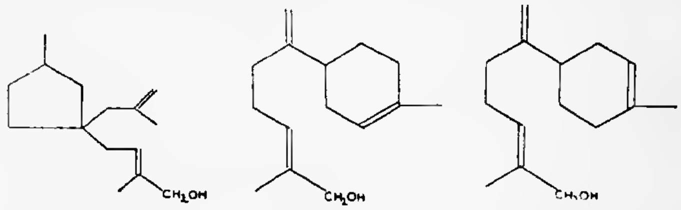


Fig. XXIII. Fig. XXIV. Fig. XXV.

It has also been shown (Birch, Mostyn and Penfold, 1953) that the oil of *Santalum spicatum* R. Br. (*Eucarya spicata* Sprague et Summ.) contains in addition to the α- and β-santalols recognised by Penfold (1928, 1932) the open-chain sesquiterpene alcohol farnesol. This explains previous observations that the sesquiterpene alcohol fractions often had a lower density refractive index and optical rotation than would be expected from a mixture of α- and β-santalols.

Phytolaccaceae

The essential oil of *Codonocarpus cotinifolius* (Desf.) F. Muell. was investigated by Bottomley and White (1950a) and (+)-*sec*butyl-*iso*thiocyanate and benzyl cyanide were identified in it. Both compounds are probably derived from mustard oil glycosides in the plant.

Rutaceae

Murray's observations (1939) on the leaf-oil of *Phebalium filifolium* Turcz. have been published (1950). It contains a substantial amount of hydrocarbon, which may be sabinene. Preliminary investigation (Bottomley and White, 1947) of the leaf oil of *P. drummondii* Benth. var. *bullatum* (J. M. Black) C. A. Gardn showed that it was of quite different type, containing mainly esters. Essential oils have been distilled from small samples of six other Western Australian plants belonging to this family (*Boronia, Eriostemon* and *Phebalium* spp.; Bottomley and White 1949) but they have not yet been examined in detail.

Myrtaceae

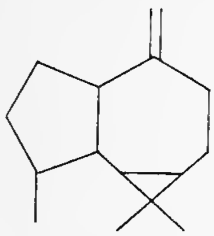
The oils obtained from three varieties of *Eucalyptus oleosa* F. Muell. ex Miq. have been described by Gardner and Watson (1948). These all give excellent yields of steam-volatile oils (see Table) with very high cineole contents. Of the 85 specimens examined only two specimens of var. *borealis* had less then 80% cineole. The var. *plenissima* particularly should be well worth cultivating commercially for its oil, especially in view of the fact that it thrives in the low rainfall areas on the eastern margin of the wheat belt.

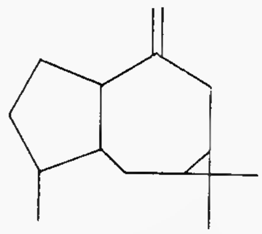
TABLE I

Oils from *Eucalyptus oleosa* vars.

Variety	No. of Speci-mens	Yield (%)		Cineole (%)	
		Range	Aver-age	Range	Aver-age
borealis C. A. Gardn.	13	2·1–4·7	3·0	72·8–92·8	86·1
kochii C. A. Gardn.	23	2·3–5·5	3·5	82·7–93·8	84·8
plenissima C.A. Gardn.	49	2·2–8·6	4·2	83·0–94·8	89·5

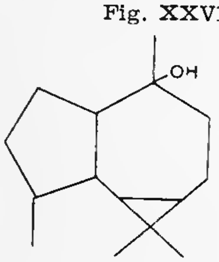
The bark of an Eastern Goldfields eucalypt reported as *E. eudesmioides* F. Muell., but which we have since learned was *E. gongylocarpa* Blakely was found by Blumann, Michael and White (1953) to contain cineole, borneol and the crystalline sesquiterpene alcohol globulol. This compound was of special interest because following the original reports of its occurrence in *E. globulus* oil residues (Schimmel & Co. 1904; Semmler and Tobias 1913), Ruzicka, Pontalti and Balas (1923) had been unable to obtain it crystalline, but concluded that unlike any other known *Eucalyptus* oil constituent, it was a derivative of cadalene.

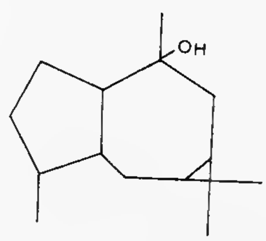




AROMADENDRENE

Fig. XXVI. Fig. XXVII.



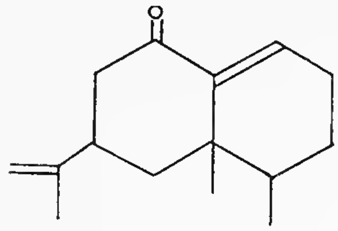


GLOBULOL

Fig. XXVIII. Fig. XXIX.

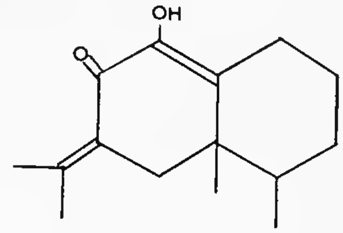
It has now been possible (Blumann *et al.* 1954) to show that in fact globulol is related to the common eucalpyt sesquiterpene aromadendrene and that like the sesquiterpene alcohol, guaiol, which is found in *Callitris* timbers, it is an azulene derivative. Taken in conpunction with Birch and Lahey's (1953) suggested structures for aromadendrene (XXVI and XXVII) two possible structures have been proposed for globulol (XXVIII and XXIX).

An examination of the essential oils of three Western Australian *Melaleuca* species carried out by Murray (1939) and already discussed by Watson (1944) has now been published (Murray, 1950). Watson (1944) noted that essential oils had not yet been distilled from 100 of our *Eucalpytus* spp., 94 of our *Melaleuca* spp. and most of the other oil-yielding genera of Myrtaceae which occur in Western Australia. Since then oils have been distilled from 12 species belonging to the genera *Balaustion*, *Chamaelaucium*, *Darwinia*, *Hypocalymma*, *Melaleuca*, *Micromyrtus* and *Thryptomene* (Bottomley and White, 1949) but lack of research workers has halted progress at this stage. I believe that it will be possible to take up these investigations again in the near future and I trust that the project will receive sufficient support to enable the vigorous prosecution of the work. The results should be of considerable interest, not only to research scientists but also to progressive industrialists and deserve to be supported and encouraged.



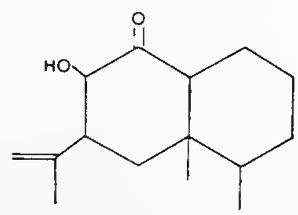
EREMOPHILONE

Fig. XXX.



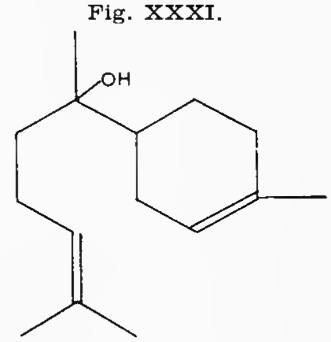
HYDROXYEREMOPHILONE

Fig. XXXI.



HYDROXYDIHYDROEREMOPHILONF

Fig. XXXII.

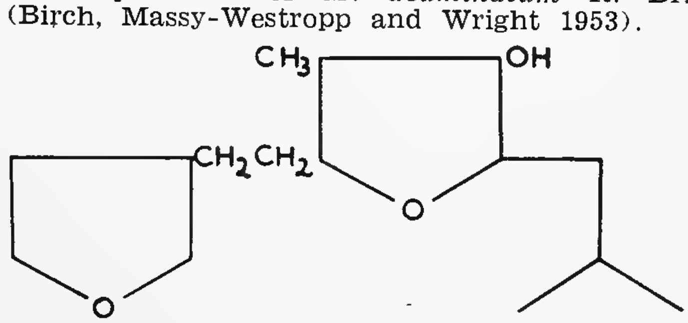


ANYMOL

Fig. XXXIII.

Myoporaceae

This family attracted attention when the Eastern Australian *Eremophila mitchellii* Benth. was reported to contain three sesquiterpene ketones (Bradfield, Penfold and Simonsen 1932) which proved to be of unusual skeletal type (XXX, XXXI and XXXII; Gillam *et al.* 1941). More recently a sesquiterpene alcohol of more normal type named anymol (XXXIII) and found to be one of the stereoisomers of bisabolol has been isolated from *Myoporum crassifolium* Forst. from New Caledonia (O'Brien *et al.* 1954) while the toxic ketone ngaione (XXXIV), first reported in *M. laetum* Forst. f. (Cunningham and Hopkirk 1945) has also been found in some specimens of *M. acuminatum* R. Br. (Birch, Massy-Westropp and Wright 1953).



NGAIONE

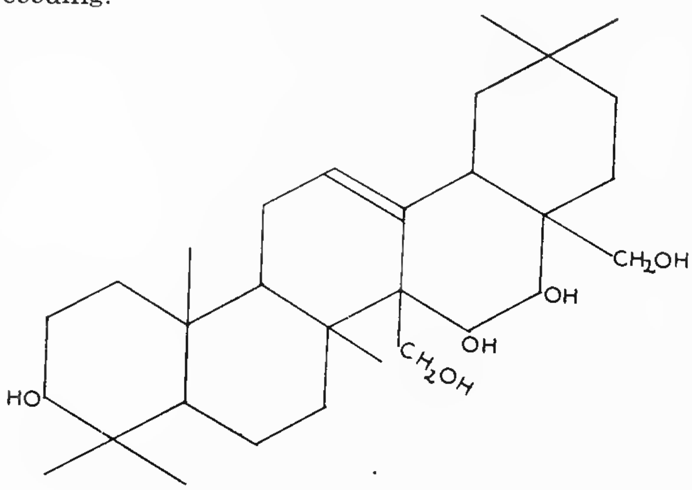
Fig. XXXIV.

No further work on the oils of Western Australian species has been published since Watson's summary (1944) in spite of the fact that several *Eremophila* and *Myoporum* species are either known or suspected to be toxic to stock.

Polyterpenoids

Pittosporaceae

Pittosporum undulatum Vent. was examined by Cornforth and Earl (1938) who isolated a triterpenoid sapogenin which they named pittosapogenin and formulated as $C_{30}H_{50}O_7$. Repetition of this work on material from plants cultivated in Western Australia yielded some of the same compound, which however proved to be a hexahydroxy-compound $C_{30}H_{50}O_6$ and was accompanied by larger amounts of a pentahydroxy compound $C_{30}H_{50}O_5$ which proved to be identical with A_1-barrigenol, obtained by Nozoe (1935) from *Barringtonia asiatica* Kurz. The constitution of the latter compound (XXXV) has recently been established (Cole *et al.* 1955) and work on the structure of pittosapogenin is proceeding.



A_1-BARRIGENOL

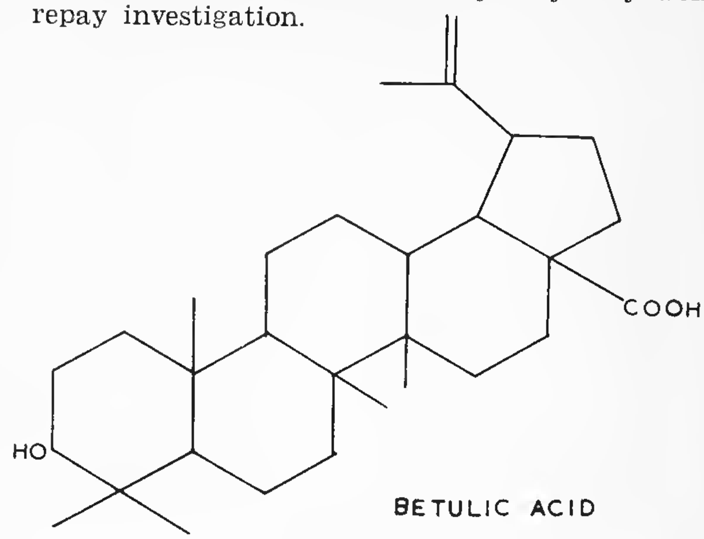
Fig. XXXV.

From the Western Australian species *P. phillyracoides* D.C., pittosapogenin has also been isolated, but in this plant it is accompanied by a compound containing only 4 oxygen atoms ($C_{30}H_{48}O_4$) which has been named phillyrigenin. This has been shown to have a primary and a secondary hydroxyl group and a six-membered lactone ring (Beckwith *et al.* 1956). Further investigations on its constitution are proceeding and investigations on other members of this family are proposed.

Euphorbiaceae

Although *Euphorbia* spp. commonly contain tetracyclic triterpenoids (Gascoigne 1955; Halsall 1955) and a hexacyclic triterpenoid has been isolated from *Phyllanthus engleri* Pax (Alberman and Kipping 1951; Barton, Page and Warnhoff 1954), *Petalostigma sericea* (R. Br.) C.A. Gardn. has been found to contain the common pentacyclic oleanolic acid in the fruits. On the other hand *Beyeria leschenaultii* (D.C.) Bail. var. *drummondii* Muell. Arg. afforded a trihydroxy diterpenoid, which has been named beyerol (Jefferies 1950). Its constitution is under investigation and it is hoped to be able to report on its structure in the near future.

Other members of this family may very well repay investigation.



BETULIC ACID

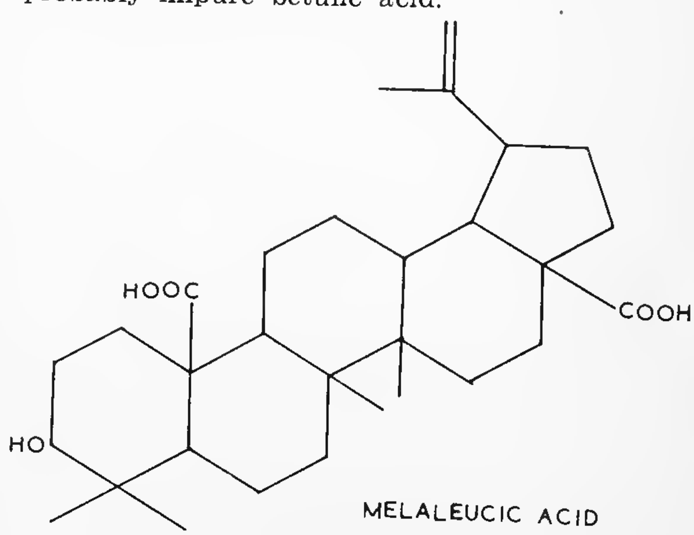
Fig. XXXVI.

Loranthaceae

The Christmas tree, *Nuytsia floribunda* (Labill.) R. Br. has been reported to contain a milky fluid (Herbert 1919) and examination of the alcoholic extract of leaves and stems revealed the presence of betulic acid (XXXVI) and a little betulin (Anstee *et al.* 1952). Betulin is a well known constituent of birch barks, and betulic acid had previously been found in one Australian and several overseas plants (*cf.* Ralph and White 1949).

Myrtaceae

The bark of *Eucalyptus calophylla* R. Br. afforded the acetate of the well-known oleanolic acid (White and Zampatti 1952) but six *Melaleuca* spp. (*M. rhaphiophylla* Schau., *M. cuticularis* Labill., *M. viminca* Lindl., *M. leucadendron* L., *M. parviflora* Lindl., and *M. pubescens* Schau.) all yielded betulic acid in the insoluble sodium salt fraction (Anstee *et al.* 1952). The first five of these species are "paper-barks" and crystalline triterpene acid can be seen in places between the papery layers of the bark. The compound isolated from *M. leucadendron* by Isii and Osima (1939) and called "melaleucin" is probably impure betulic acid.



MELALEUCIC ACID

Fig. XXXVII.

In addition three species, *M. rhaphiophylla*, *M. cuticularis* and *M. viminea* contain a second triterpene acid, which has been named melaleucic acid. It has been shown to be closely related to betulic acid and is particularly interesting as only the second triterpenoid dicarboxylic acid to have its structure established (XXXVII; Arthur *et al.* 1956).

Apocynaceae

Alyxia buxiofolia R. Br. proved somewhat unusual in that material collected at Kalgoorlie contained betulic acid, but when we attempted to isolate more betulic acid from plants collected from Point Peron we obtained a mixture of oleanolic and ursolic acids (Anstee *et al.*, 1952). This observation agrees well with the suggestion that the pentacyclic triterpenoids of the oleanane, ursane, lupane (betulic acid) and taraxastane series all arise from a common precursor (Dietrich and Jeger, 1950) as well as with the more general derivation from squalene (Eschenmoser *et al.*, 1955).

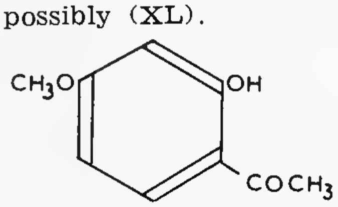
Solanaceae

Ursolic acid has been isolated from *Duboisia hopwoodii* (F. Muell) F. Muell (Trautner and Neufeld, 1947; Bottomley and White, 1951b) from *Anthotroche blackii* F. Muell and *Anthotroche pannosa* Endl. (Bottomley and White, 1950b) and it is also found together with oleanolic acid in *Anthoceris littorea* Labill. and *Anthocercis odgersii* F. Muell. while the triterpene acid mixture in *Anthocercis intricata* F. Muell. is probably similar (Anstee *et al.*, 1952).

Other Compounds

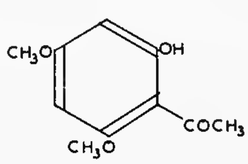
Xanthorrhoea Resins

The resins of the "blackboys" (*Xanthorrhoea* spp.) so characteristic of the Western Australian scene have engaged the attention of chemists for many years. Rennie, Cooke and Finlayson (1920) and Finlayson (1926) by steam distillation of an alkaline solution of the resin obtained paeonol (XXXVIII). It was accompanied by another crystalline compound which they called "hydroxypaeonol." Birch and Hextall (1955) have recently shown that this is, in fact, 2-hydroxy-4 : 6-dimethoxy-acetophenone (XXXIX), and have identified their xanthorrhoein as a naphthalene derivative, possibly (XL).



PAEONOL

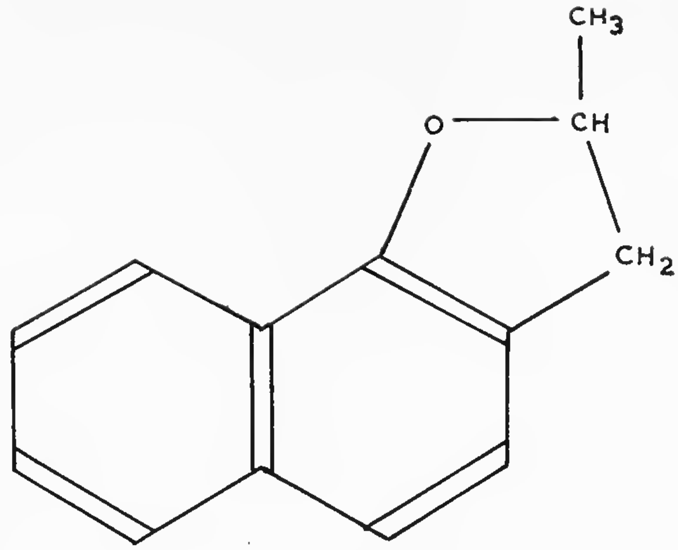
Fig. XXXVIII.



2-HYDROXY-4:6-DIMETHOXY ACETOPHENONE

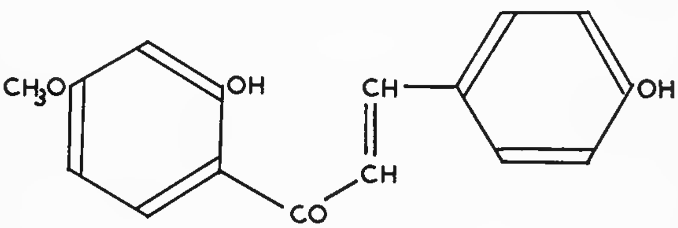
Fig. XXXIX.

Duewell (1954) suggested that paeonol might arise by alkaline decomposition of 2' : 4-dihydroxy-4'-methoxychalkone (XLI), which he isolated from *X. australis* R. Br. The same decomposition would also afford *p*-hydroxybenzaldehyde which was isolated from the resin by Bamberger (1893), while 2-hydroxy-4 : 6-dimethoxyacetophenone could well be derived from a closely related compound.



XANTHORRHOEIN

Fig. XL.



2':4-DIHYDROXY-4'-METHOXYCHALKONE

Fig. XLI.

Duewell also showed that bushfire-damaged resin yielded chrysophanic acid (1 : 8-dihydroxy-3-methylanthraquinone) and showed that this compond was produced by fire treatment. It would be interesting to know what compound in the original resin is responsible for its formation.

Future Work

It is clear from the foregoing discussion that there is no lack of problems for investigation now and in the foreseeable future.

The alkaloid field does not look particularly inviting since the alkaloid contents of our dry-country plants appear to be low, but there are still numerous plants worthy of investigation. *Anthocercis littorea* alkaloids deserve further investigation while *A. viscosa* R. Br. and some of the other species of this genus may be more interesting. Our *Senecio* and *Erechthites* spp. should be of interest in extension of the work by C.S.I.R.O. in this group of plants, whilst there are numerous *Solanum* species available in this State which should be well worthy of close study since they might provide compounds of value in the synthesis of cortisone.

Toxic plants provide many possible problems of great potential interest. There are over thirty toxic *Gastrolobium* and *Oxylobium* species alone (Garden and Bennetts, 1956) while *Stypandra, Homeria, Myoporum* and *Eremophila* are obvious choices for early investigation.

The lack of knowledge of our essential oils, I have already stressed, while the investigation of the polyterpenoid constituents of genera like *Bassia* (Chenopodiaceae), *Phyllanthus* (Euphorbiaceae) and other members of the Euphorbiaceae and the Pittosporaceae are particularly likely to yield interesting results.

All such investigations are in fact long-term projects. Even if a team of half-a-dozen workers could be put to work in each of the fields I have indicated it is unlikely that they would produce substantial results in less than three or four years and it might take twenty years to solve some of the problems but I do feel that we should be tackling the problem of investigating our native plants on some such scale as this. I believe that our group at the University has given some idea of what can be accomplished by a small group which in the early years especially was sadly lacking in experience. In spite of this and many other commitments we have published a dozen papers dealing with twenty different plants in the past 11 years. Let us set out to build onto this so that in another 30 years we will have multiplied this effort by at least twelve and we can say that most of the known problems of interest and importance are at least under investigation if not already solved.

Perhaps it is too much to hope for this in the light of our rate of progress to date. However, I feel that if we can enlist the whole-hearted support of the farmer and the pastoralist to finance work on toxic plants and of the industrial community to support investigations on alkaloids, essential oils and polyterpenoids, all of which are of potential industrial importance, then we can attract research workers by the provision of well paid posts with reasonable security. If we are successful in this we should be able to say, at least in 50 years from now, "We know the more important constituents of our common plants and we are making the best possible use of them in the interests of the community." When we can do this, I will feel that I have achieved my object in drawing your attention to these problems and enlisting your support for a vigorous effort towards their solution.

Acknowledgments

The author is greatly indebted to his colleagues and collaborators for help in the execution of the work reviewed here, and in the compilation of this summary. His own work in the field has been greatly assisted by generous support from the Department of Industrial Development, Western Australia, and the University of Western Australia as well as by a great many individual helpers who have assisted in various phases of the work from time to time.

References

Adams, R., and Rogers, E. F. (1939)—*J. Amer. Chem. Soc.* 61: 2815.

Alberman, K. B., and Kipping, F. B. (1951)—*J. Chem. Soc.* 1951: 2296.

Anet, F. A. L., Hughes, G. K., and Ritchie, E. (1953)—*Aust. J. Chem.* 6: 58.

Anstee, J. R., Arthur, H. R., Beckwith, A. L., Dougall, D. K., Jefferies, P. R., Michael, M., Watkins, J. C., and White, D. E. (1952)—*J. Chem. Soc.* 1952: 4065.

Arthur, H. R., Cole, A. R. H., Thieberg, (Miss) K. J. L., and White, D. E. (1956)—*Chem. and Ind.* 1956: 926.

Bamberger, M. (1893)—*Mh. Chem.* 14: 333.

Bancroft, J. (1872)—*Trans. Phil. Soc. Qd.* 1: 2pp.

Barton, D. H. R., Page, J. E., and Warnhoff, E. W. (1954)—*J. Chem. Soc.* 1954: 2715.

Beck, A. B., and Braden, A. W. (1951)—*Aust J. Exp. Biol. Med. Sci.* 29: 273.

Beck, A. B., Kowala, C., and White, D. E. (1956)—Unpublished results.

Beckwith, A. L., Cole, A. R. H., Watkins, J. C., and White, D. E. (1956)—*Aust. J. Chem.* 9: 428.

Bennetts, H. W. (1944)—*J. Dept. Agric. W. Aust.* 21: 104.

Bennetts, H. W. (1946)—*Aust. Vet. J.* 22: 70.

Bennetts, H. W. (1947).—*Aust. Vet. J.* 23: 10.

Bennetts, H. W., Underwood, E. J., and Shier, F. L. (1946)—*Aust. Vet. J.* 22: 2.

Biggers, J. D., and Curnow, D. H. (1954)—*Biochem. J.* 58: 278.

Birch, A. J., and Hextall, (Miss) P. (1955)—*Aust. J. Chem.* 8: 263.

Birch, A. J., and Lahey, F. N. (1953)—*Aust. J. Chem.* 6: 379.

Birch, A. J., Massy-Westropp, R., and Wright, S. E. (1953)—*Aust. J. Chem.* 6: 385.

Birch, A. J., Mostyn, K. M. C., and Penfold, A. R. (1953)—*Aust. J. Chem.* 6: 391.

Birch, A. J., and Murray (Miss), A. R. (1951)—*J. Chem. Soc.* 1951: 1888.

Birch, A. J., and Smith (Miss), E. (1956)—*Aust. J. Chem.* 9: 234.

Blumann, A., Cole, A. R. H., Thieberg, (Miss) K. J. L., and White, D. E. (1954)—*Chem. and Ind.* 1954: 1426.

Blumann, A., Michael, M., and White, D. E. (1953)—*J. Chem. Soc.* 1953: 788.

Bottomley, W. (1950)—Ph.D. Thesis, Univ. of W. Aust.

Bottomley, W., Nottle, R. A., and White, D. E. (1945)—*Aust. J. Sci.* 8: 18.

Bottomley, W., and White, D. E. (1947)—Proc. C.S.I.R. Conf. Constits. Native Plants, Melbourne.

Bottomley, W., and White, D. E. (1949)—Proc. 2nd Conf. Res. Pharmacol. Chem. Constits. Aust. Flora, C.S.I.R., Melbourne.

Bottomley, W., and White, D. E. (1950a)—*Aust. Chem. Inst. J. and Proc.* 17: 31.

Bottomley, W., and White, D. E. (1950b)—*Aust. J. Sci. Res.*, A3: 516.

Bottomley, W., and White, D. E. (1951a)—*Aust. J. Sci. Res.*, A4: 107.

Bottomley, W., and White, D. E. (1951b)—*Aust. J. Sci. Res.*, A4: 112.

Bowen, C. Y. (1944)—*J. Econ. Entomol.* 37: 293.

Bradbury, R. B. (1953)—*Aust. J. Chem.* 6: 447.

Bradbury, R. B., and Culvenor, C. C. J. (1954)—*Aust. J. Chem.* 7: 378.

Bradbury, R. B., and White, D. E. (1951)—*J. Chem. Soc.* 1951: 3447.

Bradbury, R. B., and White, D. E. (1953)—*J. Chem. Soc* 1953: 871.

Bradfield, A. E., Penfold, A. R. and Simonsen, J. L. (1932)—*J. Proc. Roy. Soc. N.S. Wales* 66: 1120.

Bradfield, A. E., Francis, E. M., Penfold, A. R., and Simonsen, J. L. (1936)—*J. Chem. Soc.* 1936: 1619.

Bradbury, R. B., and Willis, J. B. (1956)—*Aust. J. Chem.* 9: 258.

Cole, A. R. H., Downing, D. T., Watkins, J. C., and White, D. E. (1955)—*Chem. and Ind.* 1955: 254.

Cooke, R. G., and Haynes, H. F. (1954)—*Aust. J. Chem.* 7: 99.

Cooper, (Miss) J. M. (1940)—*J. Proc. Roy. Soc. N.S. Wales* 74: 450.

Cornforth, J. W., and Earl, J. C. (1938)—*J. Proc. Roy. Soc. N.S. Wales* 72: 249.

Crow, W. D. (1955)—*Aust. J. Pharm.* 36: 1402.

Crow, W. D., and Greet, Y. M. (1955)—*Aust. J. Chem.* 8: 461.

Crow, W. D., and Riggs, N. V. (1955)—*Aust. J. Chem.* 8: 136.

Culvenor, C. C. J. (1954)—*Aust. J. Chem.* 7: 287.

Culvenor, C. C. J. (1956)—Private communication.

Culvenor, C. C. J., Drummond, L. J., and Price, J. R. (1954)—*Aust. J. Chem.* 7: 277.

Culvenor, C. C. J., and Smith, L. W. (1955)—*Aust. J. Chem.* 8: 556.

Cunningham, J., and Hopkirk, C. S. M. (1945)—*N.Z. J. Sci. Tech.*, 26: 333.

Curnow, D. H., Robinson, T. J., and Underwood, E. J. (1948)—*Aust. J. Exp. Biol. Med. Sci.* 26: 171.

Curnow, D. H. (1950)—Ph.D. Thesis, University of London.

Curnow, D. H. (1954)—*Biochem. J.* 58: 283.

Curtis, R. G., Handley, G. J., and Somers, T. C. (1955)—*Chem. and Ind.* 1955: 1598.

Dietrich, P., and Jeger, O. (1950)—*Helv. Chim. Acta* 33: 711.

Duewell, H. (1954)—*J. Chem. Soc.* 1954: 2562.

Elderfield, R. C., and Gray, A. P. (1951)—*J. Org. Chem.* 16: 506.

Elderfield, R. C., and Wythe, S. L. (1954)—*J. Org. Chem.* 19: 683.

Ewing, J., Hughes, G. K., Ritchie, E., and Taylor, W. C. (1953)—*Aust. J. Chem.* 6: 78.

Emmens, C. W. (1941)—*J. Endocrinol.* 2: 444.

Eschenmoser, A., Ruzicka, L., Jeger, O., and Arigoni, D. (1955)—*Helv. Chim. Acta* 38: 1890.

Eschenmoser, A., Schreiber, J., and Keller, W. (1951)—*Helv. Chim. Acta* 34: 1667.

Finlayson, H. H. (1926)—*J. Chem. Soc.* 1926: 2763.

Fridricksons, J., and Mathieson, A. McL. (1955)—*Acta Cryst.* 8: 761.

Gardner, C. A. (1952)—*J. Agric. W. Aust.* 1: 641.

Gardner, C. A., and Bennetts, H. W. (1956)—The Toxic Plants of Western Australia—West Australian Newspapers Ltd., Perth.

Gardner, C. A., and Watson, E. M. (1948)—*J. Roy. Soc. W. Aust.* 34: 73.

Gascoigne, R. M., and Simes, J. J. H. (1955)—*Quart. Rev. Chem. Soc. Lond.* 9: 328.

Gellert, E. (1956)—*Aust. J. Chem.* 9: 489.

Gellert, E., and Riggs, N. V. (1954)—*Aust. J. Chem.* 7: 113.

Gillam, A. E., Lynas-Gray, J. I., Penfold, A. R., and Simonsen, J. L. (1941)—*J. Chem. Soc.* 1941: 60.

Gripenberg, J. (1952)—*Acta Chem. Scand.* 6: 1152.

Hartwell, J. L. (1956)—Forthcoming publication.

Herbert, D. A. (1919)—*J. Roy. Soc. W. Aust.* 5: 72.

Hesse, O. (1880)—*Liebigs Annalen* 205: 360.

Hicks, C. S., and Le Messurier, H. (1935)—*Aust. J. Exp. Biol. Med. Sci.* 14: 39.

Hillis, W. E. (1952)—*Aust. J. Sci. Res.*, A5: 379.

Hills, K. L., Bottomley, W., and Mortimer, P. I. (1953)—*Nature* 171: 435.

Hosking, J. S. (1944)—C.S.I.R. Information Section, Report T1.

Isii, M., and Osima, Y. (1939)—*J. Agric. Chem. Soc. Japan* 15: 841 (*Chem. Abstr.* 34: 767 (1940)).

Jefferies, P. R. (1950)—M.Sc. Thesis, Univ. of W. Aust.

de la Lande, I. S. (1948)—*Aust. J. Exp. Biol. Med. Sci.* 34: 181.

Langley, B. W., Lythgoe, B., and Riggs, N. V. (1951)—*J. Chem. Soc.* 1951: 2309.

Langley, B. W., Lythgoe, B., and Rayner, L. S. (1952)—*J. Chem. Soc.* 1952: 4291.

Lythgoe, B., and Riggs, N. V. (1949)—*J. Chem. Soc.* 1949: 2716.

Mann, E. A., and Ince, W. H. (1907)—*Proc. Roy. Soc.* 79: 485.

Menshikov, G. P. (1932)—*Ber. dtsch. chem. Ges.* 65: 974.

Merz, K. W., and Krebs, K. G. (1937)—*Arch. Pharm., Berl.* 275: 217.

Murray, K. E. (1939)—M.Sc. Thesis, Univ. of W. Aust.

Murray, K. E. (1950)—*Aust. Chem. Inst., J. & Proc.*, 17: 398.

Nozoe, T. (1935)—*J. Chem. Soc. Japan* 56: 689.

O'Brien, K. G., Penfold, A. R., Sutherland, M. D., and Werner, R. L. (1954)—*Aust. J. Chem.* 7: 298.

Penfold, A. R. (1928)—*J. Proc. Roy. Soc. N.S. Wales*, 62: 60.

Penfold, A. R. (1932)—*J. Proc. Roy. Soc. N.S. Wales*, 66: 242.

Pope, G. S., Elcoate, P. V., Simpson, (Miss) S. A., and Andrews, D. G. (1953)—*Chem. and Ind.* 1953: 1092.

Ralph, C. S., and White, D. E. (1949)—*J. Chem. Soc.* 1949: 3433.

Rennie, E. H., Cooke, W. T., and Finlayson, H. H. (1920)—*J. Chem. Soc.* 117: 338.

Riggs, N. V. (1949)—*J. Chem. Soc.* 1949: 3199.

Riggs, N. V. (1954)—*Aust. J. Chem.* 7: 123.

Rothera, A. C. H. (1910)—*Biochem. J.*, 5: 193.

Ruzicka, L., Pontalti, S., and Balas, F. (1923)—*Helv. Chim. Acta* 6: 859.

Schimmel & Co. (1904)—Semi-Annual Report, April/May.

Schoeller, W., Dohrn, M., and Hohlweg, W. (1940)—*Naturewiss.* 28: 532.

Semmler, F. W., and Tobias, E. (1913)—*Ber. dtsch. chem. Ges.* 46: 2030.

Shaw, F. H., and de la Lande, I. S. (1948)—*Aust. J. Exp. Biol. Med. Sci.* 26: 199.

Smith, H. G. (1896)—*J. Proc. Roy. Soc. N.S. Wales*, 30: 135.

Tominaga, T. (1953)—*J. Pharm. Soc. Japan* 73: 1175 (*Chem. Abstr.* 48: 12,741 (1954)).

Trautner, E. M., and Neufeld, O. E. (1949)—*Aust. J. Sci.* 11: 211.

Watson, E. M. (1944)—*J. Roy. Soc. W. Aust.* 30: 83.

Webb, L. J. (1948)—Coun. Sci. Industr. Res. Aust. Bulletin No. 232.

White, D. E., and Zampatti, L. S. (1952)—*J. Chem. Soc.* 1952: 5040.

White, E. P. (1951)—*N.Z. J. Sci. Technol.* B33: 50.

2.—Stratigraphy Of The Lower Murchison River Area And Yaringa North Station, Western Australia *

By D. Johnstone,† M. A. Condon†† and P. E. Playford†

Manuscript accepted—19th February, 1957

The Cretaceous sediments in the lower Murchison River area have been mapped in detail and several formations are re-defined. The "Tutula Sandstone" is demonstrated to be equivalent to the Birdrong Formation and the former name may therefore be abandoned. The Cretaceous succession is included in the Winning and Cardabia Groups.

On Yaringa North Station are exposures of Toolonga Calcilutite (Cretaceous), Giralia Calcarenite (Eocene) and Trealla Limestone (Miocene).

Introduction

The lower Murchison River area includes the country around the Murchison River and its tributaries downstream from Mount Curious on Murchison House Station. The Cretaceous sediments discussed in this paper are exposed in that area. Yaringa North Station is 8 miles south-east of the mouth of the Wooramel River. Tertiary and Cretaceous sediments outcrop in this area. The locations of the areas to be discussed are shown on Figure 1.

This paper is based on geological mapping undertaken by West Australian Petroleum Pty. Limited and the Bureau of Mineral Resources in 1954. Dr. M. F. Glaessner, Reader in Geology and Palaeontology, University of Adelaide and consultant to the above-mentioned company, and D. J. Belford of the Bureau of Mineral Resources, studied the foraminiferal assemblage of the Cretaceous formations and the ages quoted are based on their work.

Forman (1937), Clarke and Teichert (1948) and Fairbridge (1953) have previously conducted geological investigations in the lower Murchison River area.

Stratigraphy

Table 1 compares the new proposed nomenclature for the sediments of the lower Murchison area with that of previous authors.

TABLE 1.

PROPOSED NEW NOMENCLATURE			FAIRBRIDGE (1953)			CLARKE AND TEICHERT (1948)			
CRETACEOUS	Cardabia Group (Lower Part)	Toolonga Calcilutite	CRETACEOUS	Murchison House Group	Second Gully Shale	CRETACEOUS	Murchison House Series	Upper Series	Second Gully Shale
					Toolonga Chalk				Toolonga Chalk
	Winning Group	Alinga Formation			Alinga Greensand				Alinga Beds
		Thirindine Formation			Thirindine Shale				Thirindine Shale
		Birdrong Formation	PERMIAN		Tutula Sandstone				Butte Sandstone
OLDER PALAEOZOIC		Tumblagooda Sandstone			Tumblagooda Sandstone			Lower Series	Tumblagooda Sandstone

* Published with permission of the Manager, West Australian Petroleum Pty. Limited, Perth, Western Australia, and the Director, Bureau of Mineral Resources, Geology and Geophysics, Melbourne.

† West Australian Petroleum Pty. Limited, Perth, W.A.
†† Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T.

The Cretaceous sediments overlie the Tumblagooda Sandstone, which is believed to be older Palaeozoic in age, with an angular unconformity. The Tumblagooda is not discussed further in this paper.

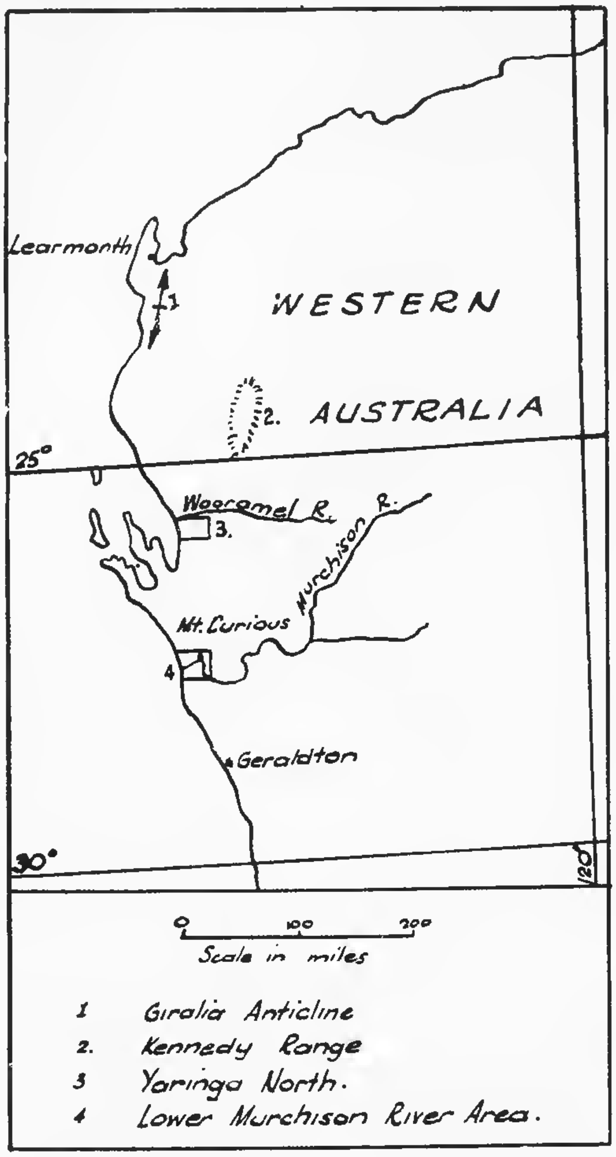


Fig. 1. LOCALITY MAP

Cretaceous

Birdrong Formation

Clarke and Teichert (1948) proposed the name "Butte Sandstone" for this Cretaceous unit and derived the name from a conical hill (a butte) at latitude 27°36′, longitude 114°9½′. As "butte" is not a geographical name and therefore invalid, Fairbridge (1953) used the name "Tutula" (from Tutula Well, latitude 27°37′, longitude 114°9′) and regarded the "Tutula Sandstone" as being Permian in age.

A comparison of the "Tutula Sandstone" with the type area (west side of the Kennedy Range) of the Birdrong Formation (Condon, 1954) shows the following points of similarity:—

1. The two formations are basal transgressive units of the Cretaceous and unconformably overlap older sedimentary formations;
2. The thickness of each of the two formations is about 100 feet;
3. Both formations are crudely bedded, poorly cemented, medium- and coarse-grained quartz sandstones with glauconite near the top;
4. Both contain pelecypods and silicified fossil wood.

These points of similarity and the fact that the Birdrong of the Kennedy Range area can be traced as an artesian and sub-artesian aquifer through dozens of water bores to the "Tutula Sandstone" of the lower Murchison River, show that the Birdrong Formation and the "Tutula Sandstone" are the same formation. Therefore, one of the names (Birdrong or Tutula) is superfluous. Although Tutula has priority because it was published first, we propose (with Dr. Fairbridge's approval) that the name Birdrong be used because:—

1. Fairbridge (1953) referred to the Birdrong Formation, although it had not been defined in a publication;
2. The name Birdrong has become widely used and is well known as an artesian and sub-artesian aquifer, and as an oil reservoir.

On the lower Murchison River the Birdrong Formation overlies the Palaeozoic Tumblagooda Sandstone with an angular unconformity of up to 2½ degrees, and underlies the Thirindine Formation conformably (see below).

Clarke and Teichert's type section at "Butte Hill" is poorly exposed and we propose that the well exposed section at "Bidgie Bidgie Point" (latitude 27°34′, longitude 114°13′) become the reference section for the lower Murchison River.

The section of the Birdrong Formation at "Bidgie Bidgie Point," in descending order, is:—

Thirindine Formation

1 foot	Greensand, fine-grained, silty, sandy, green.
7 feet	Sandstone, quartz, coarse and medium, silty, glauconitic, yellow; fossil bone and wood.
33 feet	Sandstone, quartz, medium and coarse, grey.
22 feet	Sandstone, quartz, fine-grained, well sorted, grey.
36 feet	Sandstone, quartz, medium-grained, poorly sorted, grey, some glauconite.
3 feet	Sandstone, quartz, medium-grained, poorly sorted, yellow.
3 feet	Siltstone, sandy (coarse-grained).
2 feet	Sandstone, coarse-grained, poorly sorted, and conglomerate, fine quartz, yellow; in basal 6 inches are ¼-inch rounded pebbles of sandstone from Tumblagooda Sandstone.
	Tumblagooda Sandstone
107 feet	

The top one to three feet of the Birdrong is sandy, glauconitic, silty and slightly calcareous, and possibly may be equivalent to the Muderong Shale of Condon (1954).

Fossil bone and *Teredo*-bored fossil wood occur in the Birdrong Formation. At Pillarawa Hill (latitude 27°28½′, longitude 114°17½′) pelecypods were collected in the top 18 feet. At present the age of the formation can be determined only by reference to its position relative to the overlying Cretaceous formations, the ages of which are known from foraminifera. The Birdrong Formation is regarded as being possibly Neocomian in age.

Thirindine Formation

Clarke and Teichert (1948) proposed and defined the Thirindine "Shale". The name was taken from Thirindine Point (latitude 27°36′, logitude 114°11½′).

The formation consists of alternating 1 to 3-foot units of moderately hard radiolarite with glauconite, and soft, grey and green radiolarian siltstone, and shale with glauconite. As the Thirindine "Shale" of Clarke and Teichert has several lithologies interbedded and is not mainly shale, it is renamed Thirindine Formation.

Clarke and Teichert restricted the Thirindine to the white, hard beds of "siliceous shale". This "siliceous shale" (radiolarite) is interbedded with radiolarian shale and claystone, and the overlying sediments all contain abundant radiolaria and are fine-grained and thin-bedded to laminated. Only the greensand at the base of the Alinga Formation as here defined is sufficiently distinct in lithology to make a satisfactory formation boundary. For these reasons the Thirindine Formation is extended up to the base of the basal greensand of the Alinga Formation.

The Thirindine Formation is conformable with the underlying Birdrong Formation and the overlying Alinga Formation.

The Thirindine Formation is better exposed at Toolonga Point than at Thirindine Point and we suggest that the type section be at Toolonga Point where the section, in descending order, is:—

Alinga Formation

16 feet	Shale, soft, dark grey, radiolarian, carbonaceous, bentonitic.
27 feet	Interbedded radiolarite, soft, pale brownish-grey, thin-bedded, bentonitic, and shale, soft, dark grey, laminated, radiolarian, bentonitic.
29 feet	Radiolarite, white, interbedded moderately hard to soft, thin-bedded to laminated; little glauconite.
3 feet	Interbedded radiolarite, white, moderately hard, thin-bedded, and siltstone, grey, bentonitic, laminated; Belemnites.
2 feet	Radiolarite, white, moderately hard, glauconitic;

Birdrong Formation

77 feet

Radiolaria are common, and belemnites, pelecypods, ammonites and fossil wood occur in the basal 25 feet of the formation. An examination of the microfauna suggests a probable age of Aptian (Lower Cretaceous).

Alinga Formation

Clarke and Teichert (1948) proposed and defined the "Alinga Beds" and derived the name from Alinga Point (latitude 27°37′, longitude 114°7½′). Fairbridge (1953) renamed the unit "Alinga Greensand". Although the Alinga is glauconitic it is mainly glauconitic siltstone with some beds of glauconitic sandstone and of greensand. We propose therefore to rename the unit Alinga Formation.

The Alinga Formation consists of green, glauconitic siltstone (in places carbonaceous), glauconitic fine-grained sandstone and dark green greensand. The base of the Alinga is taken at the base of the greensand.

The formation conformably overlies the Thirindine Formation and disconformably underlies the Toolonga Calcilutite.

The type section at Alinga Point, in descending order, is:—

Toolonga Calcilutite

3 inches	Bed with phosphatic nodules.
10 feet	Siltstone, clayey, glauconitic, green and grey.
31 feet	Siltstone, glauconitic, carbonaceous, dark grey; Belemnites.
9 feet	Greensand, fine- and medium-grained, clayey, dark green.

Thirindine Formation

50 feet

More accessible exposures of the Alinga Formation are at "Bidgie Bidgie" and Thirindine Points.

The Alinga Formation is correlated with the Gearle Siltstone of Condon *et al.* (1956). The microfauna of the Gearle and Alinga Formations indicates an Albian to Cenomanian age.

Toolonga Calcilutite

Clarke and Teichert (1948) defined the "Toolonga Chalk" and named it after the Toolonga Hills (latitude 27°34′, longitude 114°12½′). They also proposed and defined the "Second Gully Shale" which conformably overlies the Chalk.

Clarke and Teichert had difficulty in mapping the "Second Gully Shale" and apparently never saw a good exposure of it or of its contact with the "Toolonga Chalk." The Second Gully is a calcilutite and the boundary between the chalk and the calcilutite is difficult to map with certainty both in outcrop and in the water bores to the north of the lower Murchison River area.

Therefore, we propose that the name Toolonga, which is well known geologically, be applied to Clarke and Teichert's Toolonga and Second Gully formations. As the lithology throughout the area is mainly a calcilutite the formation is called the Toolonga Calcilutite.

The formation overlies the Alinga Formation disconformably. Its top is generally travertinised at the Tertiary erosion surface.

The type section is two miles north of Yalthoo Well at latitude 27°35½', longitude 114°10½'. The section, in descending order, is:—

Travertine

17 feet	No outcrop.
5 feet	Calcilutite, light greenish-yellow, soft, with flint nodules.
12 feet	Calcilutite, light greenish-yellow, soft, "shaly" appearance, bright green clay in pockets and "veins."
26 feet	Calcilutite, light green, soft, bedded (3 to 4 inches); *Gryphaea, Ostrea,* Echinoid Spines, and small fragments of *Inoceramus* in basal 12 feet.
25 feet	Chalk, massive, yellow-white, and white, with flint nodules. *Marsupites, Uintacrinus, Inoceramus* fragments.

Alinga Formation

85 feet

Three miles south-west of the Yaringa North Homestead are exposed 50 feet of green calcilutite which is the top part of the Toolonga Calcilutite.

The foraminiferal assemblage and the *Marsupites* and *Uintacrinus* fix the age of the chalk as Santonian. The foraminifera of the calcilutite show that the age is Campanian. The basal 10 feet of the calcilutite is transitional from the Santonian to the Campanian.

Winning, Cardabia and Murchison House Groups

After mapping the Cretaceous formations on the Giralia Anticline and on the west edge of the Kennedy Range, Condon, Johnstone, Prichard and Johnstone (1956) defined the *Winning Group* as consisting of the Muderong Shale, Windalia Radiolarite and the Gearle Siltstone. A disconformity occurs at the top of the Winning Group.

We propose the inclusion of the Birdrong Formation in the Winning Group, which then constitutes a sedimentational unit starting with a transgressive sand above an unconformity and finishing at the next unconformity. As thus redefined the Winning Group comprises, in ascending order, Birdrong Formation, Muderong Shale, Windalia Radiolarite and Gearle Siltstone.

Two of the Cretaceous formations of the lower Murchison River can be broadly correlated with those of the Winning Group, e.g., the Thirindine Formation with the Windalia Radiolarite, and the Alinga Formation with the Gearle Siltstone.

Condon *et al* (1956) defined the *Cardabia Group* as "the sediments which disconformably overlie the Gearle Siltstone of the Winning Group and disconformably underlie the Giralia Calcarenite. The group is characterized by calcarenites, generally glauconitic, with minor calcilutites, marl, and greensand."

The upper part of the Toolonga Calcilutite is similar in lithology and age to the base of the Korojon Calcarenite (of Condon *et al.,* 1956) and the Toolonga may therefore be included in the Cardabia Group.

It is proposed that the "Murchison House Group" of Fairbridge (1953) be abandoned and that the terms Winning and Cardabia Groups be extended to the lower Murchison River area.

The Birdrong, Thirindine and Alinga Formations are included in the Winning Group, and the Toolonga Calcilutite is included in the Cardabia Group.

Eocene

Giralia Calcarenite

On Yaringa North and Wooramel Stations are isolated outcrops of Giralia Calcarenite (of Condon *et al.,* 1956) which are not in contact with any other formation.

The lithology is yellowish-green glauconitic limestone with foraminifera *(Discocyclina),* Bryozoa, echinoids, pectens and brachiopods.

Small outcrops of the Giralia occur 6¾ miles east-north-east of Wooramel Homestead and 6¾ and 8¾ miles north-east of Yaringa North Homestead. The thickest exposure is about 10 feet.

Miss I. Crespin of the Bureau of Mineral Resources, Canberra, examined samples and found *Discocyclina* and *Asterocyclina,* which denote a Middle to Upper Eocene age.

Miocene

Trealla Limestone

Hard, grey, crystalline limestone of the Trealla Limestone (Condon, Johnstone and Perry, 1953) outcrops from 4 miles south to 1½ miles north of Yaringa North Homestead. The maximum thickness is 25 feet.

The Trealla Limestone disconformably overlies the Toolonga Calcilutite but it was not seen to overlie the Giralia Calcarenite.

Miss I. Crespin examined samples and found the foraminiferal assemblage characteristic of the Lower Miocene Trealla Limestone.

References

Clarke, E. de C., and Teichert, C. (1948).—Cretaceous Stratigraphy of Lower Murchison River Area, Western Australia. *J. Roy. Soc. W. Aust.* 32: 19-48.

Condon, M. A. (1954).—Progress Report on the Stratigraphy and Structure of the Carnarvon Basin, Western Australia. *Bur. Min. Resour. Aust. Rep.* 15: 1-163.

Condon, M. A., Johnstone, D., and Perry, W. J. (1953).—The Cape Range Structure, Western Australia. *Bur. Min. Resour. Aust. Bull.* 21: 1-82.

Condon, M. A., Johnstone, D., Prichard, C. E., and Johnstone, M. H. (1956).—The Giralia and Marrilla Anticlines, North West Division, Western Australia. *Bur. Min. Resour. Aust. Bull.* 25: 1-86.

Fairbridge, R. W (1953).—"Australian Stratigraphy." Univ. of W. Aust. Text Books Board, Crawley.

Forman, F. G. (1937).—Artesian and Sub-artesian Water Possibilities, Woodleigh Station, Murchison District. *Ann. Prog. Rep. Geol. Surv. W. Aust.,* 1936: 9-11.

3.—Wave-Cut Platforms At Yampi Sound, In The Buccaneer Archipelago, W.A.

By A. B. Edwards *

Manuscript accepted—19th February, 1957

The section of the Northwest coast of Western Australia that lies between King Sound and Collier Bay, and which includes Yampi Sound and the Buccaneer Archipelago, is a drowned or submergent coast, with narrow, nearly straight, sub-parallel sounds or inlets, up to 5 or 10 miles long, extending out into channels between chains of islands (Fig.1). The rocks of the region are folded to overfolded mica schists, chlorite schists, quartzites, hematite quartzites, and occasional beds of hematite, intruded in parts of the mainland by sills of quartz-felspar porphyry (Canavan and Edwards, 1938). The long axes of the sounds or inlets, the channels, and the chains of islands trend more or less northwest, parallel to the strike of the major fold axes. From King Sound to Yampi Sound the coast trends at right angles to these structures, and is of the *Ria* type. From Yampi Sound east to Collier Bay, however, the coast parallels these structures, so that this section of the coast is of the *Dalmatian* type.

Apart from a few small pocket beaches, and some protected and mangrove-infested inlets, the coastlines are cliffed, the cliffs ranging in height from a few feet to several hundred feet, according to the composition of the rocks and the dips of the beds. The islands and the mainland are generally bounded by fringing coral reefs, in places narrow, but up to 200 yards wide.

The average tidal range in this region is about 30 ft., increasing to 33 ft. at spring tides, and up to 36 ft. at "king" tides; and to a height of 30 ft. above the reef level the rocks are stained black. The striking horizontal black band that results extends up from the inner level of the reef to the average high water mark all around the rocky coast of the islands and the mainland, and contrasts strongly with the buff, ochreous, brown, red-brown and white rocks immediately above it (Fig. 2). At close quarters the top of the black band cannot be defined over a depth of about 12 in., but seen from 100 ft. or more, it appears as a sharp line, and provides a useful datum by which to compare the height of the occasional rock stacks and the many rock platforms that occur along sections of the coast.

The waters within the sounds and in the channels are commonly calm or mildly choppy, with waves only occasionally reaching a height of 4 ft., even in exposed positions. During the wet season (summer), however, the region is subject to winds from the N. and N.E. of up to 100 miles per hour, when all exposed sections of the coast are subjected to violent wave attack.

Strong S.E. winds blow occasionally at other times in King Sound, to the west of the Archipelago, but fail to produce comparable storms, although they give rise to rough seas in the western approaches of the Archipelago.

Rock Platforms

Rock platforms are a feature of the coasts of a number of the islands, and of long sections of some of the inlets. These platforms end abruptly on their landward sides against vertical cliffs. Their surfaces are horizontal or slope to seaward at 5° - 10°, and at their seaward edges end abruptly in "a low tide cliff", or more commonly in a ramp inclined at 25° - 45°. The surfaces of the platforms are invariably at or just below the top of the black band, i.e., the mean high tide level, so that they are covered at spring tides on calm days.

Platforms along Inlets

Platforms at mean high tide level extend along both cliffy walls of some of the long narrow inlets or sounds, like Copper Mine Inlet. The platforms are 5 to 15 ft. wide, and resemble parallel roads cut in the cliffs at high tide level. Their surfaces are relatively smooth, and horizontal, or have a gentle slope seaward. They end abruptly in a steep slope to the low tide level.

Two features of these platforms seem significant:—

(i) They extend up the inlet to a point where the inlet becomes choked with mangroves, and for considerable parts of their lengths there is a growth of mangroves on their steeply sloping seaward edge. This mangrove growth is thin and stunted where it is nearest to the open sea, but becomes a more vigorous growth further up the inlet. Evidently the wave action required to cut these platforms, and maintain them, is a very weak one.

(ii) The platforms are found only where the walls of the inlet consist of quartz-felspar porphyry or of schists. Where the walls consist of quartzites, the platforms cease abruptly, and a smoothly sloping bare rock wall is present, with no notch at the high tide level.

* C.S.I.R.O., Melbourne

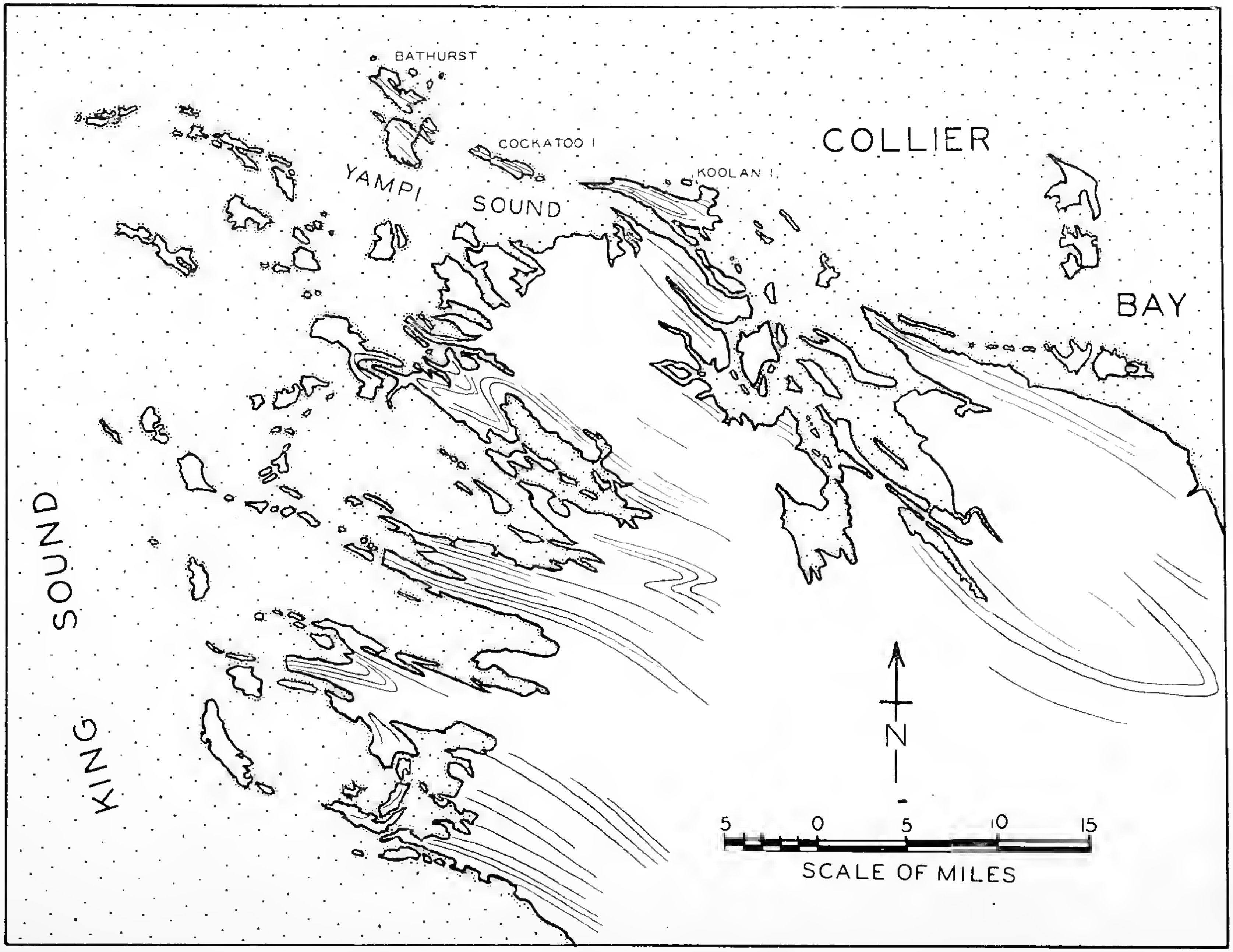


Fig. 1—Sketch map of the coast between Collier Bay and King Sound showing the relation between the strike lines of the sedimentary formations and the form of the coastline.

The porphyry and the schists are both deeply weathered to the high water mark (the top of the black band). The groundmass of the porphyry, and its felspar phenocrysts are generally severely kaolinized down to this level, i.e. to the surface of the platform. Where the porphyry is strongly jointed, this weathering permits easy undercutting of the jointed blocks. Where the joints are more widely spaced erosion of the more kaolinized rock along the joints leaves tors of relatively fresh rock, 4 to 5 ft. in diameter. Below the high water mark, the porphyry is fresh and unweathered, and is much harder and tougher than the kaolinized rock.

Fig. 2.—Nares Point, west of Koolan Island, showing the "black band", at low tide. *(H. Owen, photo.)*

Similarly the schists are weathered to soft buff and brown clayey rocks down to the high tide mark, but are unweathered and much tougher below this level.

Fig. 3.—Platform about 100 ft. wide, with rock stacks, on a small island on the northern side of Bathurst Island. *(H. Owen, photo.)*

The quartzites, by contrast, are little affected by weathering, and show no apparent difference in hardness or toughness above or below the high tide level. Moreover, they are generally harder than either the fresh porphyry or the fresh schist.

It appears, therefore, that the essential factor leading to the formation of these platforms (or rock terraces) is the pronounced softening and weakening that the porphyries and schists undergo on weathering in a tropical climate (with about a 60 inch rainfall). This weathering ceases abruptly at the mean high tide level, below which level the rocks in the cliffs are permanently wet, and so are preserved from weathering. Even the weakest of waves are able to take advantage of this abrupt change in hardness, where it exists, and cut a platform at high tide level.

Platforms on the Islands

The most striking development of platforms is found on small rocky islets in moderately sheltered positions. Many of them are "hat-shaped," consisting of a central core with vertical yellow or grey cliffs rising 10 ft. to 50 ft. above a flat black fringing platform from a few feet to 50 ft., or even 100 ft. wide. This platform ends on its seaward side in either a "low tide cliff" or more commonly, a steep, well defined and uniformly sloping bevel or ramp that continues down to reef level. The surfaces of the platforms may be smooth or irregular, according to the disposition and relative hardness (and composition) of the sediments involved. Occasionally they carry small rock stacks.

As along the inlets, the rocks are weathered down to the high tide mark (the top of the black band), but are practically unweathered below this level, and the surfaces of the platform coincide more or less with the base of the zone of weathering.

In places the "core" of weathered rocks has been completely eroded, leaving extensive flat black rock platforms, which are submerged at spring high tides, but are exposed in varying degree at other stages of the tide.

Some of the islands, notably the more southerly groups in the Archipelago, consist essentially of white quartzites, and these lack platforms, presumably because weathering does not induce any significant change in hardness at high tide level.

Pronounced platforms occur, also, on a number of exposed islands in the vicinity of Yampi Sound proper. These islands consist of quartzites and hematite quartzites interbedded with micaceous and chloritic schists. Here several factors appear to influence the formation of rock platforms (a) rock hardness, and (b) the disposition of the beds, and (c) the height of the cliffs.

The influence of rock hardness (and susceptibility to weathering) is well revealed along the exposed northern coasts of Koolan Island and Cockatoo Island, where there is a much stronger development of high tide mark platforms where schists are present at this level than where hematite quartzites form the cliffs.

The effect of disposition of the beds is well seen on McIntyre Island, Irvine Island, Bathurst Island, and the group of small islands tied by reefs to the northern side of Bathurst Island (Fig. 1). On Bathurst Island, particularly on the southern side, the coast consists of high vertical cliffs. On its western side massive beds of hematite quartzite and quartzite dip seawards at 30° or more. This section of its coast consists of smooth rock ramps running up the dip slopes. Commonly such a ramp is continuous with the slope of the island surface to 100 ft. or so above the high tide mark. Equally commonly the ramp ends in a "cliff" from 5 to 20 ft. high, whose face is at right angles to the slope of the ramp, the "cliff" having formed where a massive bed has been quarried away by the waves along a master joint at right angles to the bedding. The surfaces of some of the ramps are broken by a series of more or less closely spaced joints trending at right angles to the seaward edge.

On the northern sides of these islands however, where the dips are flatter and landwards, prominent platforms are developed, particularly on the small headlands that separate the indentations and occasional pocket beaches. Where the rocks in the platforms are thin bedded and of different hardness the platform surface is correspondingly irregular, but where the rocks are of uniform hardness, the platform surface is flat and relatively horizontal. Some platforms are up to 100 ft. wide (Fig. 3).

The platforms tend to be wider where they are backed by low cliffs than where they are backed by high cliffs, presumably because the volume of rock to be eroded at high tide is less, and a wider platform can be cut before high tide and low tide erosion forces balance. Possibly, also, the intensity of weathering of the rocks above high tide mark may be greater where the cliffs are low. The broadest platforms are those marking former small islands or tied islands, from which all rocks projecting above the high tide mark have been eroded.

Origin of the Platforms

These rock platforms bear a considerable resemblance to the rock platforms occurring at about high water mark along the coasts of Tasmania and south-eastern Australia. These platforms on the southern coasts are attributed variously to wave action (Edwards, 1941; 1951) and to the effect of "water layer levelling" (Hills, 1949). There has been some tendency to think of them as marking (measuring) a post-glacial eustatic fall of sea level (Fairbridge, 1954), but this explanation cannot be extended to the platforms in the vicinity of Yampi Sound, in view of the distinctly higher reduced level of the Yampi platforms.

There seems little doubt that many of the Yampi platforms owe their origin to wave action operating at a level where there is a sudden change from soft to hard rocks. This change occurs abruptly at the mean high tide level, below which level the rocks are permanently saturated with water and unweathered.

Such platforms are identical in character and origin with the "Old Hat" type of shore platform described by Bartrum (1935).

The length of time during which waves can erode at high tide level is of short duration during any one tide level, since the tide rises or falls at the rate of about 1 in. per minute. This is reflected in the bevelled seaward edges (ramps) of the platforms. The most vigorous erosion of the cliffs above the high tide level must occur during periods of storm coincident with periods of high tide. This must apply particularly along those sections of the island coasts that are fully exposed to storms.

These rock platforms on the exposed islands reveal a transition from the "Old Hat" type of platform, where the weathered state of the rock down to high tide level and its abrupt change at this level to hard fresh rock, are the dominating factors, to the "storm wave" platform proper, in which the rocks above the platform are unweathered, but are, in their fresh state, within the hardness range necessary to yield such rock platforms under the conditions of wave attack to which the coast is subject (Edwards, 1941).

The Yampi rock platforms are clearly not the outcome of a post-glacial eustatic fall of sea-level, since the sea level could scarcely fall 30 ft. at Yampi Sound, and only 15 ft. along the south-eastern coast of Australia; and they might be regarded as indirect proof that the

similar platforms occurring at about high tide level within the narrower tidal range along the southern coasts of Australia are simple erosion features, and equally independent of any eustatic movement of sea level.

It seems reasonable, therefore, to regard these platforms, like those of the southern coasts of the continent, as "storm wave platforms", and to see them as a normal stage in the maturing of a cliffed coastline where there is an appropriate relation between rock hardness, cliff height and the intensity of wave attack.

Acknowledgments

The observations recorded were made during a brief visit to Yampi Sound as a guest of the Broken Hill Proprietary Co. Ltd. My thanks are due to the Company for providing the facilities to examine these platforms, and to the geologists of the Company who accompanied me, particularly Mr. Ian Reid and Mr. Hubert Owen for taking photographs of relevant features. The strike lines shown in Fig. 1 are taken from an aerial mosaic of the region.

References

Bartrum, J. A. (1935).—Shore Platforms, *Rep. Aust. N.Z. Ass. Adv. Sci.*, 12: 135-143.

Canavan, F., and Edwards, A. B. (1938).—The Iron Ores of Yampi Sound, *Proc. Aust. Inst. Min. Met.*, No. 110.

Edwards, A. B. (1941).—Storm Wave Platforms, *J. Geomorph.*, 4: 223-236.

Edwards, A. B. (1951).—Wave Action in Shore Platform Formation, *Geol. Mag.*, 88: 41-49.

Fairbridge, R. W. (1954).—Quaternary Eustatic Data for Western Australia and Adjacent States, *Proc. Pan Ind. Ocean Sci. Congr.*, Perth, August, 1954, Sect. F; 64-84.

Hills, E. S. (1949).—Shore Platforms, *Geol. Mag.*, 86: 137-152.

4.—Jointing Associated With The Hampton Fault Near Madura, W.A.

By M. J. Frost*

Manuscript accepted—19th February, 1957

Jointing exposed in, and controlling the shape of, a cave about six miles south of the Hampton Escarpment is shown to be consistent with downwarping to the south. Evidence for the scarp being produced by normal faulting is reviewed and it is suggested that the jointing is associated with and pre-dates such faulting.

Introduction

The Eucla Basin, of flat-lying Cretaceous and Tertiary sediments, occupies an area of over 40,000 square miles in the south-east of Western Australia and a smaller area in South Australia. It may be divided into two physiographic regions separated by its only prominent feature, the Hampton Escarpment. These are a northern region, the Nullarbor Plain which is a plateau rising slightly to the north, and a southern, the Eyre Coastal Plain.

Stratigraphy

Fairbridge (1953) correlating bore logs has suggested the following sequence:

Formation	*Thickness at Madura*
Eucla Limestone	930 ft.
Hampton Conglomerate	24 ft.
Disconformity	
Madura Shale	over 1100 ft.
Loongana Conglomerate	?
Unconformity	
Precambrian Complex	

The Madura Shale is Cretaceous, diagnostic macrofossils (Teichert, 1947) and microfossils (Raggatt, 1954) having been found in shales of this formation at Loongana and Cook, respectively. The microfossils at Cook are well-preserved Lower Cretaceous foraminifera identical with those found throughout the Great Artesian Basin (Crespin, 1955).

Singleton (1954) has divided the Eucla Limestone into two formations, an upper hard limestone up to 100 ft. thick, the Nullarbor Limestone, and a lower chalky limestone rich in sponge spicules and exposed up to 240 ft., the Wilson Bluff Limestone (presumably named after Wilson Bluff about 20 miles east of Eucla).

Miss Crespin (1956) has shown from a study of the foraminifera that the Nullabor Limestone at Eucla can be divided further into an upper formation of hard foraminiferal crystalline limestone and a lower formation of hard bryozoan limestone. The upper is over 40 feet thick and "contains an assemblage of foraminifera which is found in the Trealla Limestone of the Carnarvon Basin and is typical of "f_1"-"f_2" stage in Indo-Pacific Tertiary stratigraphy. It is equivalent to the upper part of the Lower Miocene." The lower hard bryozoan limestone is about 40 feet thick and "the lithology is characteristic of that found in the Giralia Calcarenite in the Carnarvon Basin. There is little doubt that these rocks are upper Eocene in age." Foraminifera from specimens presumably of the Wilson Bluff Limestone were also shown to indicate upper Eocene age.

Nature and Significance of Jointing

The jointing which forms the subject of this paper has been observed at only one locality, in a cave which has been called the Madura South Cave. This cave is about six miles south of the Hampton Escarpment at Madura and is on the Eyre Coastal Plain. It is one of the shallower caves of the basin having a maximum depth of about 65 ft. below the plain level and not reaching the water table. Since only very small areas of the Eucla Basin have been subject to even preliminary geological investigation it cannot be definitely stated that similar jointing is not exposed elsewhere, but in the deep caves of the Nullarbor Plain, of which Murra-el-ellivan, Cocklebiddy, and Abracurrie were visited, no such jointing was noticed. It is probable, however, that widely-spaced joints and lines of weakness occur over large areas.

The jointing in the Madura South Cave is made evident by erosion along the joint planes. On the inside of the cave this tends to produce a series of elongate chimneys and on the outside wide cracks or, less commonly, solution pipes. Where the two join there is in one instance considerable widening to produce a small intermediate cave. Few of the joints are perfectly planar, most curving to give gentle horizontal rolls, but the average dip is always vertical. Since the straight passages of the cave are obviously parallel to joint directions, and in several instances actually follow joints, their directions are included in Table I and were used in computing the mean directions of the joint sets.

The pattern developed (Fig. 1) consists of four joint sets which are interpreted as two conjugate shears bisected at right agles by one compression and one tension set. This pattern is that usually developed in homogeneous rocks under stress. There is some controversy over the interpretation of the theoretical pattern but here, where flow is not believed to have been important and where jointing took place at shallow

* Department of Geology, University of Western Australia.

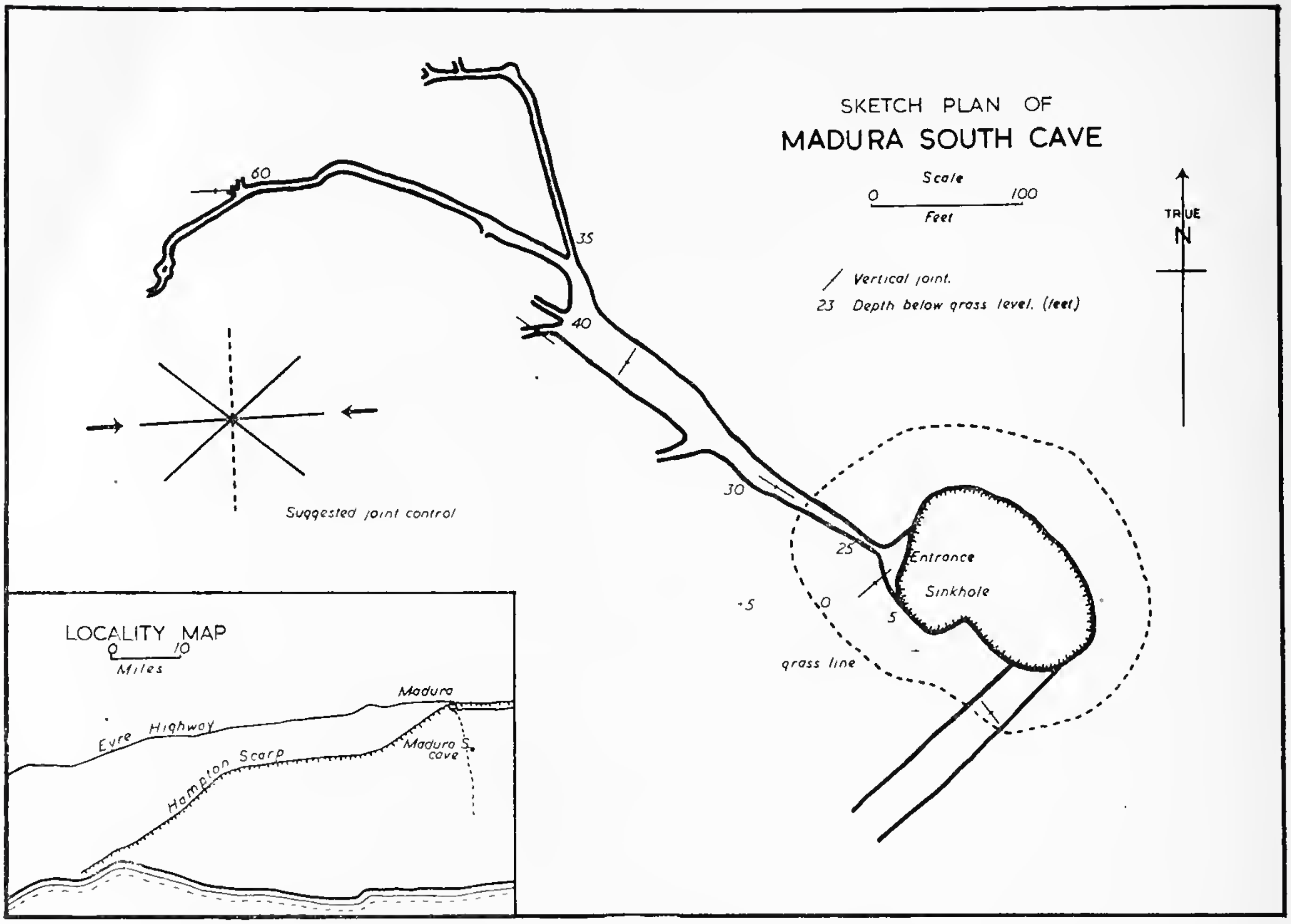


Fig. 1

depths there is little doubt that the stress hypothesis applies and that the acute angle between the conjugate shears is bisected by the axis of maximum stress. As may be seen from Table I there are certain deviations from the ideal; thus the compression set is represented only by a cavern direction and varies by about 11° from the ideal and the shear sets seem to be split into two separate pairs. The latter is easily explicable as due to a change in stress, and the former variation might be expected for any

TABLE I.

Strikes of joints and passage directions in Madura South Cave

Strikes		Mean of strike directions	Suggested type of joint
Joints	Main passage directions		
33°	51°	48 ± 7*	Shear
49°	49°		
87°	....	87°	Tension
126°	119°	128 ± 7	Shear
142° ±	131°		
	165°	165	Compression

* Mean deviation.

single joint. Not much importance can be attached to such aberrations, the surprising feature is not that they exist but that they are so slight. The two conjugate shears are particularly well developed with their acute angles to the east and west. From this it is inferred that at the time of jointing the axis of intermediate stress was vertical and that of minimum stress, N.-S. It is possibly this joint system which controlled the orientation of the elongate dark patches on the ground (trending N.E.-S.W., 40 miles south of Forrest and E.N.E.-W.S.W. and N.W.-S.E. concurrently 36 miles S.E. of Cook) seen from the air by Woolnough (1933). No indication of the loading which applied that stress can be obtained from the jointing alone without reference to the regional history.

It is obvious from the considerable thickness of moderately shallow water sediments preserved in the Eucla Basin (at least 2000 ft.) that the area has had a fairly continuous negative isostatic tendency since the Cretaceous. It is crossed by three south-facing escarpments, the Hampton Escarpment, the Bunda or Great Bight Escarpment which faces the sea and is almost certainly the continuation of the Hampton Escarpment, and the submarine escarpment in the Great Australian Bight. Woolnough (1933) and Gentilli and Fairbridge (1951) suggest that each of these is a fault scarp whereas Maitland (1919) and Singleton (1954) consider both the Bunda and Hampton Escarpments to be the

result of marine erosion. The evidence for the two southern escarpments being fault scarps is mainly physiographic and will not be considered here. The evidence for, the existence of the Hampton Fault is both physiographic and stratigraphic.

The linear tendency of the scarp face, the plains of similar rocks at levels differing by about 300 ft. on either side of the scarp and the typical fault scarp physiography all suggest faulting.

Bore logs from Transcontinental Railway bore No. 3, 337 miles, 61 chains (near Loongana), Madura No. 2 (30 miles north of Madura) and Madura No. 1 (30 chains south of the scarp at Madura) suggest a drop in succession of over 300 feet (Fig. 2). The marker horizons are the

It is important to know whether the postulated fault predates or postdates the jointing. As may be seen from Fig. 1 the lineaments of the scarp, taken from the Australian Aeronautical Map, June 1944, closely parallel the joint directions and strongly suggest that the faulting postdates joint formation.

The lack of dissection of the plateau and the fact that thick post-Miocene sediments have not been recorded suggest that the present surface was probably never heavily loaded by superimposed sediments. Under such conditions compressional loading, of magnitude suitable to form joints, would have produced a horizontal axis of intermediate strain, the direction of easiest relief being upwards. Since the jointing indicates the presence of a vertical axis of inter-

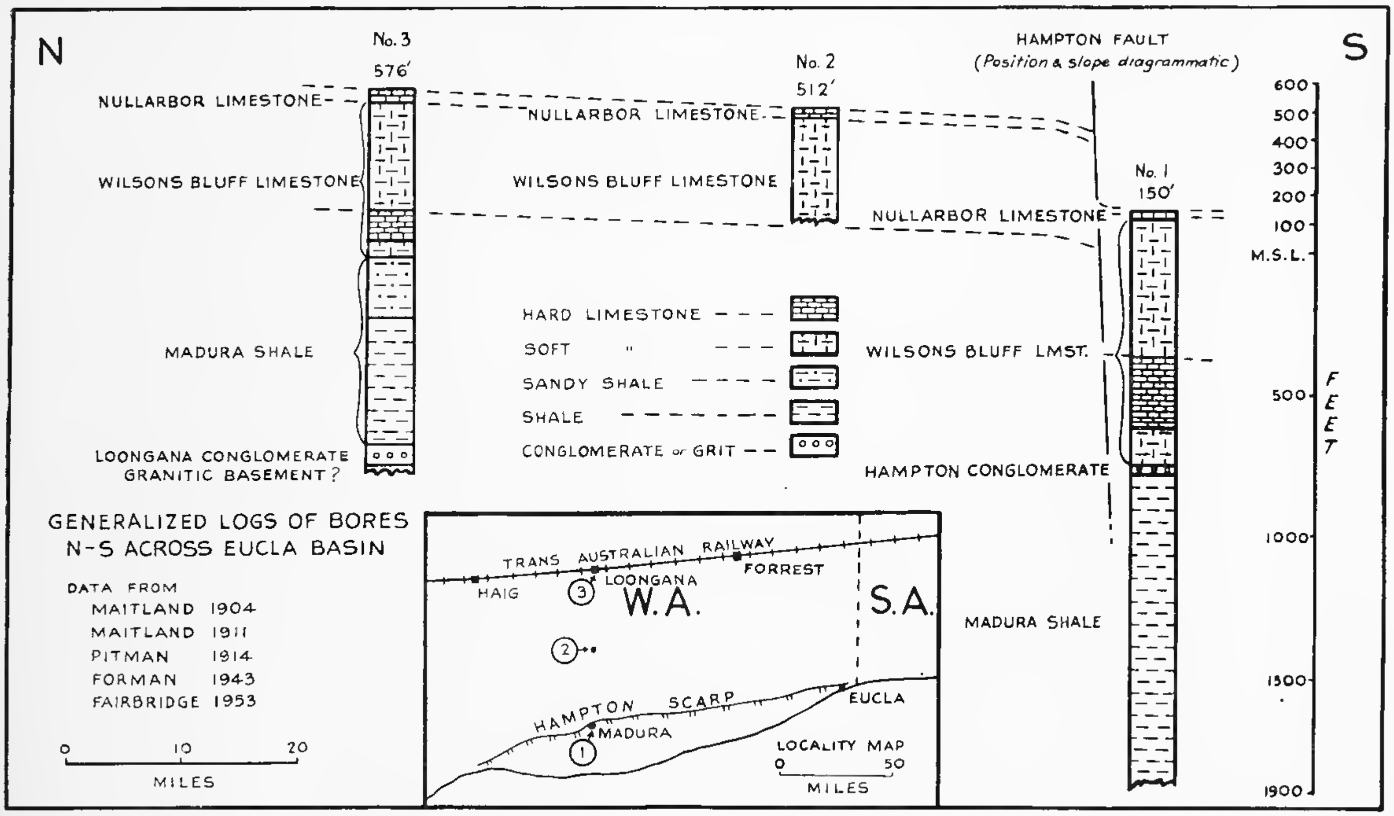


Fig. 2

base of the Nullarbor Limestone and the top of an unnamed hard limestone member in the Wilson Bluff Limestone. The Madura No. 2 bore is not deep enough to cut the second marker horizon but as a hand-boring plant was used it is probable that the bore stopped at the hard limestone member, which is represented in both the other bores. A second bore near Loongana using a hand-boring plant also stopped at this hard member.

The log of the Transcontinental Railway bore No. 3, 337 miles 61 chains (near Loongana) has not previously been published in full and is quoted in Table II for convenience (Forman, 1943).

Taken together the physiographic and stratigraphic evidence leave little doubt that the Hampton Scarp represents the surface cxpression of a young fault with a downthrow to the south of over 300 ft.

mediate strain there remain the possibilities of either shearing or tensional loading. The possibility of shearing loading cannot be entirely ruled out but it was obviously not in operation at the time of formation of the Hampton Fault, unless the angular outcrop was caused by secondary faulting, and since its direction would have to be either N.E.-S.W. or N.W.-S.E. it is difficult to see any feature with which it could be associated.

Tensional loading seems the most probable explanation. Such tension could be produced in three ways:—regional tension, tension due to drag on faults, or tension on an upper axis of an anticlinal warp. Regional tension would not be expected to produce close jointing so near to the surface. There is no evidence of faulting near the cave except the Hampton Fault which postdates the jointing. We know that the basin has had a tendency to downwarp to the south so it seems probable that local warping also

TABLE II.

Transcontinental Railway bore No. 3 at 337 miles 61 chains

R.L. of surface 576 ft. above sea level.

Depth below surface in ft.	Description of strata	Remarks
0— 3	Soil	Boring commenced 12/8/1909
3— 50	Hard limestone with blow holes	
50— 65	Soft limestone	
65— 67	Hard limestone	
67— 405	Soft limestone	Rest level of local water 295 ft.
405— 430	Soft limestone with hard bands	Water level (artesian) 420 ft.
430— 530	Hard limestone with flints	
530— 630	Soft limestone with flints	
630— 813	Soft green sandy shale	
813— 816	Hard bands of shale	
816— 857	Sandy shale with small hard bands	
857— 860	Hard bands of shale	
860— 890	Soft sandy shale	
890— 892	Hard bands of shale	
892— 905	Soft sandy shale	
905— 910	Hard bands of shale	
910—1270	Soft puggy shale	
1270—1344	Fine and coarse sand with hard bands of granite boulders	Artesian water struck in this stratum stands in bore at 420 ft. from surface.
1344—1370	Decomposed granite	
1370—1372	Hard granite	

took place. That such warping should predate any important faulting also seems very probable and suggests that this was the mechanism that produced the jointing.

It may therefore be concluded that the jointing is due to tensional forces on the upper axis of an anticlinal warp associated with sinking to the south which was followed by the production of a normal fault, the Hampton Fault.

Acknowledgments

My thanks are due to Mr. Quartermaine, of the Kalgoorlie School of Mines, who generously made available his maps and knowledge of the area, to members of the party who assisted in the exploration and mapping of the cave, to Dr. R. W. Fairbridge for his advice and comments, and Dr. J. J. E. Glover for critically reading the manuscript.

References

Crespin, I. (1956).—Fossiliferous rocks from the Nullarbor Plains. *Bur. Min. Resour. Aust. Rep.* 25: 26-42.

Crespin, I. (1955).—Letter to Dr. R. W. Fairbridge dated Aug. 15th, 1955.

Fairbridge, R. W. (1953).—"Australian Stratigraphy." 2nd ed. University of W. Aust. Text Books Board, Crawley.

Forman, F. G. (1943).—Letter to Prof. E. de C. Clarke dated March 29, 1943.

Gentilli, J., and Fairbridge, R. W. (1951).—Physiographic Diagram of Australia. New York (The Geographical Press).

Maitland, A. G. (1904).—Artesian Water, Eucla Division. *Ann. Prog. Rep. Geol. Surv. W. Aust.* 1903: 33-34.

Maitland, A. G. (1911).—Results of boring for artesian water on the Eucla Plateau. *Ann. Prog. Rep. Geol. Surv. W. Aust.* 1910: 13-14.

Maitland, A. G. (1919).—A summary of the geology of Western Australia. *Geol. Surv. W. Aust.* Mem. 1 (The Mining Handbook) Ch. I. 55 pp.

Pittman, E. F. (Chairman) (1914).—Report of the second interstate conference on artesian water. Brisbane (Govt. Printer).

Raggatt, H. G. (1954).—The search for oil in Australia and New Guinea. *Aust. Inst. Min. Met. Review Lect.* No. 2 (Suppl. to Bull. 172).

Singleton, O. P. (1954).—The Tertiary Stratigraphy of Western Australia—a Review. *Proc. Pan Ind. Ocean Sci. Congr. Perth.* 59-65.

Teichert, C. (1947).—Stratigraphy of Western Australia. *J. and Proc. Roy. Soc. N.S.W.* 80: 81-142.

Woolnough, W. G. (1933).—Report on aerial survey operations in Australia during 1932. Canberra (Commonwealth Govt. Printer).

5.—Clastic Dykes From Watheroo, Western Australia

By Brian W. Logan*

Manuscript accepted—20th August, 1957

At Watheroo a series of narrow clastic dykes has been injected into the Archaean granitic basement from the overlying Capalcarra Sandstone. The sediment forming the dykes, a first cycle orthoquartzite, has been derived from a weathered mantle overlying the crystalline rocks. The suggested mechanism of emplacement is by the slumping of unconsolidated sands into fissures in the granite which have opened under local tension stress associated with the instability in the basement rocks of the depositional area.

Introduction

Sedimentary (clastic) dykes intrude porphyritic microcline granite on an unconformity surface at Watheroo, a small town 140 miles north of Perth. The orthoquartzite forming these dykes is lithologically identical with the basal orthoquartzite unit of the Capalcarra Sandstone (Logan and Chase, 1956, ms.). This formation is the basal component of the Moora Group sediments which unconformably overlie the crystalline rocks on the periphery of the West Australian Precambrian shield in a sequence of approximately 4,000 ft. thickness.

The narrow northtrending belt of Moora Group outcrop which has been traced from its southern extremity at Moora as far north as Coorow was stratigraphically subdivided for the first time in 1956 by R. L. Chase and the author into four conformable formations of sandstone, siltstone, arkose and chert—the basal formation being the Capalcarra Sandstone to which the dykes are lithologically related. Proterozoic and Ordovician ages have been suggested for the Moora Group but the fossil evidence is uncertain so that both ages must be regarded as unsubstantiated.

Location and Description

The sandstone dykes are exposed in a small 1½ acre granite outcrop, 30 yards west of the Geraldton Highway, 3 miles north of Watheroo. The outcrop represents a slight upward undulation of the unconformity surface which has been stripped to form a granite inlier in the Capalcarra Sandstone surrounding it. The reader is referred to figure 1, a geological map of the sandstone dyke locality which shows the distribution of the dykes and a series of small shears which intersect them.

The clastic dykes, with the exception of one narrow north-north-west-trending dyke are subparallel and trend approximately E.-W. They commonly persist along their length for distances of 15 to 20 yards before thinning out or merging with a thin superficial soil which partially obscures the Capalcarra Sandstone outcrop. The width of the dykes varies from half an inch up to 8 inches; the average width is approximately 2 inches. The dykes are generally vertical but occasional steep dips of 80 to 85° N. and S. are recorded.

Although the dyke orthoquartzite is strongly cross-jointed the lack of cataclasis along the contacts indicates that the dykes have suffered little or no movement along their walls since lithification. They are, however, cut by N.N.E. and S.S.E. trending shears which have caused minor horizontal displacement (1 to 15 inches) of the dykes in some cases. Other dykes may

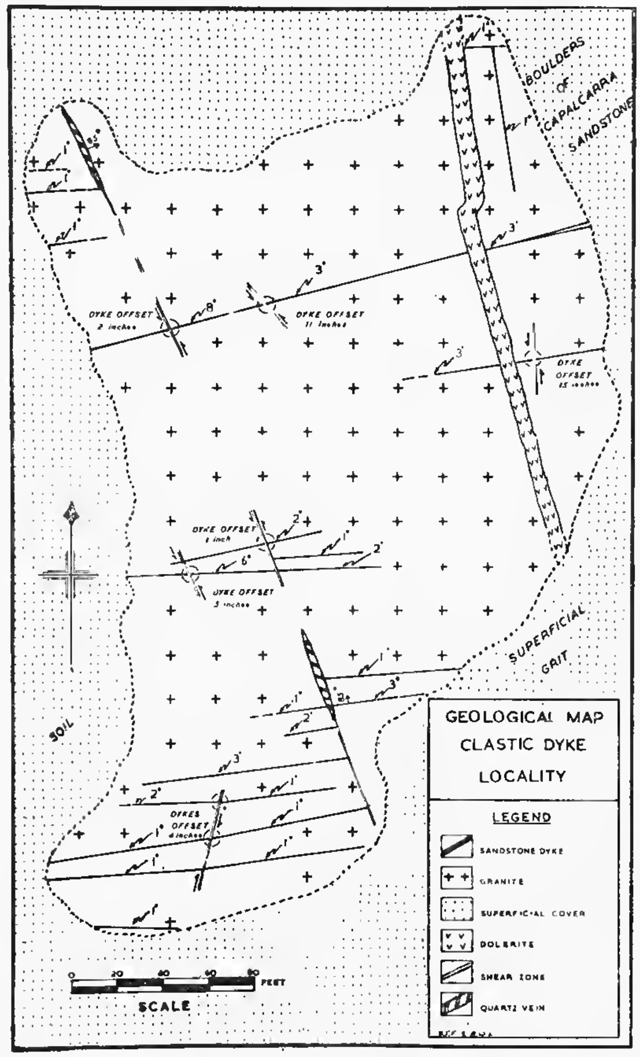


Fig. 1.—Geological map of clastic dyke outcrop at Watheroo.

cross the shear without apparent horizontal displacement. The movements may also have a small vertical component for there is often a difference in dyke width on opposite sides of the shear. The Watheroo area is a block-faulted terrain with a dominent west-block-down displacement but since no data are available on the behaviour of the sandstone dykes at depth generalisation as to the nature and extent of the movements that have effected the dykes is not possible.

A series of dolerite dykes intrude the Moora Group strata and a small dolerite dyke cuts across the sandstone dykes. The earlier shearing movements were accompanied by quartz emplacement in some of the shears.

* Department of Geology, University of Western Australia.

Petrography

The dyke material is a pink massive orthoquartzite of the first cycle with quartz making up more than 95% of the detrital fraction, 2% detrital microcline and an interstitial cement of authigenic sericite (Fig. 2). Secondary overgrowth of authigenic quartz on the detrital quartz grains has occurred but the original grain shape is well delineated by lines of minute, indeterminate inclusions. The grains were apparently well-rounded, and size sorting is poor; grain diameter ranges from 0.2 to 0.85 mm., the average grain diameter being approximately 0.5 mm.

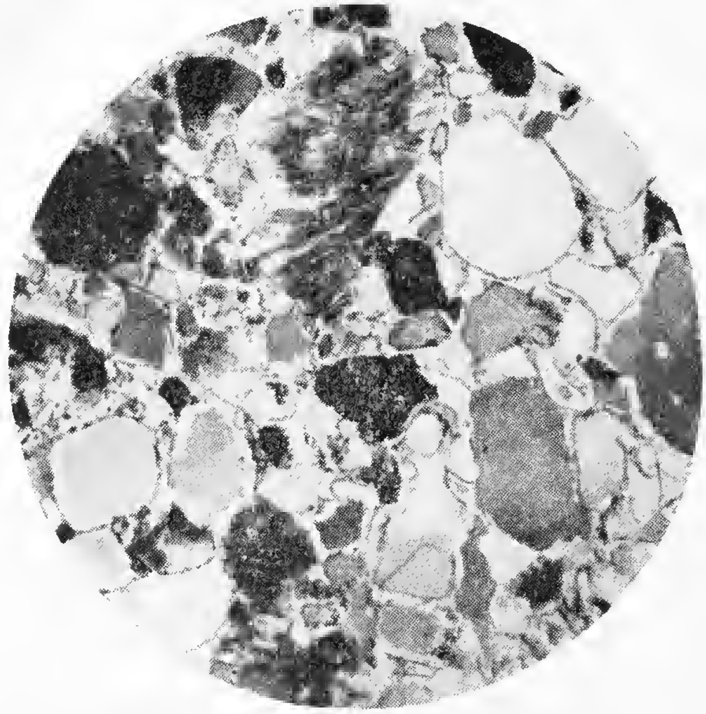


Fig. 2.—Photomicrograph, X 25. Orthoquartzite from a sandstone dyke at Watheroo. Note the secondary overgrowth of quartz on the detrital grains and the large detrital fragment of feldspar.

Three types of quartz grains are present: (a) quartz grains containing dark equant inclusions; (b) quartz grains with inclusions of acicular rutile; (c) quartz grains with internal suturing, denoting their derivation from vein quartz. All three features are consistent with the derivation of the grains from a metamorphic complex of granite and granitic gneiss. Microcline is present as tabular grains of 0.7 to 1.0 mm. average size. Sericite has been developed authigenically on both feldspar and quartz and the host granite has also suffered sericitisation.

Formation of the Dykes

Provenance

The orthoquartzite in the dykes is lithologically identical with the basal unit of the Capalcarra Sandstone in the area. This formation with its variable thickness and wide lateral and vertical variation in lithology from poorly-sorted arkoses and arkosic conglomerates to orthoquartzites has the characteristics of a basal sand formed by the winnowing of a weathered rock mantle (regolith) under the strand line conditions which transgressed the granitic craton area. The quartzose detritus shows evidence of fairly extensive working in the high degree of rounding of the grains. Detrital feldspar on the other hand is similar in grain size to the microcline of the host granite and the angularity of the grains points to an *in situ* origin for this component. Nor is the poor sorting of the detritals consistent with prolonged transportation and it seems that wave action is the most likely agent of deposition.

Mechanism of Injection

The small S.S.E. and N.N.E. shears are especially significant in considering the emplacement mechanism of the dykes. The dykes and shears are probably co-genetic and contemporaneous, formed by *local* tensional stress, directed normal to the trend of the dykes, i.e. N.-S. tensional stress, which was relieved by opening of the dyke fissures and by smaller auxilliary movement along the shear directions. The fissures once opened were immediately filled by slumping into them of mobile water-saturated Capalcarra sands which were overlying the moving basement. In one case a small dyke was emplaced in the S.S.E. trending shear direction.

Vintage (1954) considered that sandstone dykes intruding granites in Colorado formed by injection of clastic material from above along submarine faults, i.e. these dykes were formed after the granite and gneiss had been covered by sediments and before the lithification of the latter. The dykes in Colorado are, however, much larger and more extensive than the Watheroo dykes and they have pronounced cataclasis at their edges; they are emplaced in fault zones. The Watheroo dykes are much smaller and have not suffered later movements along their edges. However, the massive unstratified and homogeneous nature of the orthoquartzite indicates a slump origin for these also, rather than emplacement by slow washing in of clastic material into open joints on a pre-Capalcarra surface, a process which would produce stratification in the dykes. Fairbridge (1946) points out that sandstone dykes are commonly associated with slumping and are related to movement contemporaneous with sedimentation. Certainly the dykes occur in a zone of instability, being adjacent to the Darling Fault and within the shatter zone of this major rift. Such an instability in the depositional area is not only indicated by the sandstone dykes, but is mirrored in the lower formations of the Moora Group where arkose and tuffaceous siltstones predominate.

Acknowledgements

My thanks are due to my co-worker in the Moora Group project—Mr. R. L. Chase, to Mr. D. J. Forman who assisted in mapping the outcrop and to Professor R. T. Prider and Dr. J. J. E. Glover for critically reading the manuscript.

References

Fairbridge, R. W. (1946).—Submarine Slumping and Location of Oil Bodies. *Bull. Amer. Ass. Petrol. Geol.* 30, (1): 84-92.

Logan, B. W., and Chase, R. L. St. L. (1956).—Geology of the Moora Area and Stratigraphy of the Moora Group. Faculty of Science, University of Western Australia. (Unpublished thesis.)

Vintage, P. W. (1954).—Sandstone Dikes in the South Platte Area, Colorado. *J. Geol.* 62, (5): 493-500.

INSTRUCTIONS TO AUTHORS

Papers may be submitted to the Society in accordance with Rules and Regulations 38 to 41 inclusive (see below). They should be addressed to *The Honorary Secretary, Royal Society of Western Australia, Gledden Building, Perth.*

Authors are solely responsible for the factual accuracy and for any opinion expressed in their papers. They are particularly requested to verify references.

In the preparation of MSS. authors are required to follow the C.S.I.R.O., *Guide to Authors* (C.S.I.R.O., Melbourne, 1953), except that papers longer than 10,000 words (30 foolscap pages of pica type, with 6 inch lines 40 to the page) will not normally be accepted.

Authors are required to meet half the cost of preparation of the blocks required to reproduce all diagrams and illustrations.

Authors shall receive a total of 30 reprints free of charge. Further reprints may be ordered at cost, provided that such orders are submitted with the MS.

RULES AND REGULATIONS

38. Every paper intended to be read before the Society or to be published in the Society's Journal must be sent to the Secretaries at least seven days before the date of the next ensuing Council meeting, to be laid before the Council. It will be the duty of the Council to decide whether such contribution shall be accepted, and if so, whether it shall be read in full, in abstract, or taken as read. All papers accepted for publication must be read or otherwise communicated at an ordinary meeting prior to publication.

39. A Publications Committee, appointed by the Council, shall recommend to the Council whether a paper presented to the Society shall be published in the Society's Journal. The Publications Committee may obtain an opinion from any person it may select on the suitability of any paper for publication.

40. Publication in the Society's Journal shall only be available to *(a)* Ordinary Members, *(b)* Honorary Members, *(c)* Non-members resident outside Western Australia, who must communicate the paper through an Ordinary or Honorary Member. No paper shall be accepted from a Non-member resident in Western Australia.

41. The original copy of every paper accepted for publication by the Society, with its illustrations, shall become the property of the Society, unless stipulation is made to the contrary, and authors shall not be at liberty to publish their communicated papers elsewhere prior to their appearance in the publications of the Society unless permission for so doing is given by the Society, or unless the Society fails to publish the paper in the Journal of the year in which it is read or otherwise communicated, or of the succeeding year.

Journal

of the

Royal Society of Western Australia, Inc.

Volume 41 1958

Part 1

Contents

Editor: J. E. Glover

Annual Subscription: Thirty Shillings

The Royal Society of Western Australia, Inc., Gledden Building, 731 Hay Street, Perth

8131/1/58—450

By Authority: ALEX. B. DAVIES, Government Printer, Perth